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METALLURGIA

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Reconversion of Industry to Peace Time Needs

SINCE the acceptance of the terms of surrender by Germany and Japan, industry in the many countries concerned has been trying to adjust itself to peace conditions, but the success so far achieved is not of a high order. While this applies to Britain as well as to other countries, there is no indication that industrial recovery in this country is in any worse condition than elsewhere, but her problems are different from the other countries concerned and these seem to give the impression that less is being done to speed recovery. It must be remembered that while the other main countries concerned are practically self-supporting, Britain must import to live, indeed, she must import many of the raw materials to enable her industries to function and to permit her to manufacture the goods needed to pay for imports. Thus, exports are more vital to her than the United States or the U.S.S.R.

During the war years Britain sacrificed more than any other country to achieve victory. Her progress during this time has been viewed with justifiable satisfaction, but her industries were almost wholly concerned with the war effort and it is common knowledge that of the forces which interfere with industrial progress, war is the most disastrous. It is true that, in certain directions, the technique of production may make remarkable progress in promoting increased facilities for the prosecution of war, but these tend to unbalance industry when peace-time activities are resumed. War seriously interferes with the whole organisation of trade and industry built up slowly and laboriously in times of peace and forces countries that were dependent on industrialised countries like Britain for machinery and other manufactured goods, to give more attention to their own industrial needs and to erect plant for that purpose.

When vast portions of the world's surface are so disturbed that the products of the soil and the mines can not be developed or utilised, when the energy of man is wasted on destruction, industrial progress must be diverted into artificial channels, and the supply of raw materials and man power lessened so seriously as to affect the whole world. The artificial industrial conditions resulting from the war necessitated various controls under the defence emergency powers, and these created many difficulties, especially in the early stages of the war. That there should be a desire for the removal of these controls, now that the war is over, is understandable, but there is still dislocation of supplies from one cause or another and these artificial conditions are likely to remain until the adjustment between supplies and demand is approximately reached.

That there is need for speed in reconverting industry to peace-time needs none will deny, but some statements made in the press during recent weeks give the impression that the dislocation in peace-time trade and industry caused by six years of war can be remedied by a stroke of the pen. We seem to remember that similar statements were made during the early years of the war, when industry was doing its utmost to supply the needs of the Forces, but it was not until the end of 1943 and beginning of 1944 that organisation of industry had reached the desired level of output. Changing from war to peace-time activity is not less difficult than organising industry for war and the need is just as urgent. It behoves everyone, therefore, who gives priority to Britain's interests, to study her industrial problems and to assist their early solution.

Mention has been made of the need for continuing control, if only to prevent the chaos experienced after the last war, but, obviously, they should be organised and operated to facilitate the smooth inflow of supplies and to provide channels for the smooth outflow of production. The recent decision to operate the controls for a further five years is an indication of the importance given to this aspect by the Government and of the time they regard recovery will involve. Providing they are operated in the interests of industry as a whole and with the least possible delay, they will assist a planned recovery, but this question of controls will undoubtedly be raised in Parliament many times within the next few years.

The Government has taken a further step to assist reconversion by retaining the Regional Boards formed in the war. Hitherto, the function of these Boards has been chiefly concerned with the production of munitions, consequently, their interest has been mainly in the engineering and allied industries, and more recently they have been concerned with the transition from munitions production to production for civilian needs. With the end of the Ministry of Production, general responsibility for the Regional Boards has now passed to the Board of Trade. The Boards have been useful, not only as a machinery for the co-ordination of Regional activity, but in linking together central policy with local opinion and in dealing with a variety of unforeseen emergencies for which no regular procedure existed. In adapting the constitution and functions of the Board to peace-time conditions, the Government is anxious to preserve these benefits, but is satisfied that to do so in peace-time the Boards must be strictly advisory in character.

In future the Boards will exercise their activity over the whole field of productive industry. Under the new constitution the Boards have been renamed "Regional Boards for Industry." Each will consist of an impartial chairman, together with three representatives each of employers and trade unions, and the senior representatives of the Board of Trade, Admiralty, Ministries of Supply and Aircraft Production, Labour, War Transport, Fuel and Power, Food, Works and Town and Country Planning and, in Scotland, the Scottish Office. Representatives of other Departments will attend meetings when matters in which they are interested are being discussed under their terms of reference, the Boards will

advise Ministers upon industrial conditions within the Regions, and upon steps which may be necessary to bring regional resources in productive capacity or labour into fuller use. In addition, working parties are to be formed in particular industries with the object of facilitating production. Whether these will do what they are intended to do depends very much on the spirit in which they will function, certainly we must guard against the running of industry by committees.

These efforts to plan reconversion, although they are causing some uneasiness in industry, do show that action is being taken to avoid the difficulties experienced after the last war. That Britain has shown remarkable resilience during the war is well known. The credit is largely due to the commonsense and steadfastness of her people, but there is abundant evidence that her institutions have proved stable and adaptable under difficult conditions. These factors will have great value in the trying times ahead. It is true that the war will have changed the world's industrial demand, but despite the fact that Britain's dependency on export trade makes her peculiarly vulnerable to political and economical influences, she will adapt her industrial life to the changes and the same qualities which overcame the production problems of the war will be used to restore her industrial activity to peace-time needs.

Imperial Preference and British Export Trade

THE most serious of all the many problems which face Britain, said the Rt. Hon. L. S. Emery, at a recent meeting of the Institute of Export, is that of earning a living. The future of the world, as well as our own future, lies, not in the attempt to resuscitate the promiscuous internationalist system of the last century, but in building up a better balanced world economy. The foundation of such an economy must lie in the creation, first of all, in a reasonable internal balance by the several nations and, then, in their building up by the mutual co-operation and association with others, more particularly those with whom they are connected by common interests and common ideals in the sphere of policy and defence, a wider balance and thus creating larger unities providing the maximum opportunities for economic expansion and at the same time in a position without danger to their own economic stability to develop fruitful trade intercourse with other comparable unities.

More particularly, continued Mr. Emery, the post-war situation will offer to all the partners in the British Commonwealth and Empire an unequalled opportunity for an expansion which should eventually exceed even that of the United States or of Russia, in view of the greater advantages which we possess, both in the extent and diversity of our resources and in the organised ability and enterprise at our disposal. That expansion need not follow the American principle of capitalist individualism and unrestricted free trade within a single tariff. Still less is it likely to follow the rigid State collectivism of the Soviet system. It would naturally be far more decentralised, affording scope in each part for such measure of local protection as may be desirable in order to create a full and balanced development of local resources, as well as for such free choice between socialist and individualist methods as may suit the needs or political outlook of each community. Such a decentralisation, indeed, is essential, as this war has shown, in order to afford a corresponding decentralisation of defensive strength. We can be only too grateful for what Dominion tariffs, coupled with inter-Imperial preferences, have done to save the situation in this war. And we are no less bound, in order to give a better balance to our internal economy to give effective protection to our own agriculture even against Empire competition. What is essential is that the preferential system of the future should provide the co-ordination and concentration of the surplus purchasing and investing power of each part upon the development of the rest. And it can do so without prejudice to each part also developing its trade relations outside the Empire. The question is one, not of exclusion, but of priorities.

In conclusion, he said, there lies before us an opportunity, greater than ever offered itself to any group of nations in the world. Who has the right to forbid us to avail ourselves of that opportunity or to enforce on us a policy which, in my opinion at least, can only spell disaster for us and for the world? The nations of our Commonwealth, standing together in arms, saved the world. Who dare tell us that we may no longer support each other in mutual peaceful co-operation? Or who among us is so short-sighted or so mean spirited as to submit to such a veto from any nation, however friendly, as the price of immediate ease? There can be no greater injury to the cause of good relations with the United States, let alone to the unity of the Empire, than to allow it to be thought that Imperial Preference is a subject which we are even prepared to discuss with any outsider. That is the key of our own household which we cannot hand over to strangers. That is our birthright which we cannot sell for any mess of pottage.

British Goods for the New Age

THE announcement that the Government has accepted a proposal from the Council of Industrial Design to hold a national exhibition of design in the summer of next year is a happy augury for the future and a prelude to an exhibition of greater magnitude to embrace all sections of British industry. This design exhibition will not be anything so vast or all-inclusive as a commercial exhibition or trade fair; it will represent the best that modern British industry can produce, largely the new post-war designs, but not excluding those good designs of the years immediately before the war which will be going into production again.

This exhibition will be British industry's first great post-war gesture to the British people and to the world. It will demonstrate the vigour, freshness, originality and skill with which our manufacturers are setting about their task of serving the home consumer and capturing a great share of the export trade. The British public will see what industry has planned. The world overseas will discover that the brains, ingenuity and taste which long gave Britain her place as a leader of world industry have not deserted her, and that her lead will be kept.

In addition to peace-time goods, it is intended to show the public as much as possible of the achievements in war production of industries normally making consumer goods, and the way in which war-time developments in manufacturing technique and processing has led on to the new designs and types of goods which post-war industry would produce.

An Examination of the Effect of Rate of Loading on the Ultimate Tensile Strength and Elongation of Magnesium Alloys

By J. L. Walker

Much work has been carried out with the object of determining the effect of different rates of loading on the yield point and ultimate stress when making tensile tests on materials. Most of this work has been concerned with steels, copper and copper alloys, and to some extent aluminium alloys. The present report describes experiments and results of an examination of the rate of loading on tensile tests of magnesium alloys.

THE importance of control of rate of loading or straining when making tensile tests on most materials is well known. A great deal of work has been carried out on this subject by many investigators,[1-6] mainly with the object of determining the effect of different rates of loading on yield point and ultimate stress; the effects on elongation and reduction in area have also been examined. Most of the work has been carried out on various steels and on copper, brass and some aluminium alloys, and the general conclusions have been that the values for both yield point and ultimate stress are increased with increases in the loading rates. The rates of loading, or testing speeds investigated varied from the extremely high speeds obtained in the impact tension test, when a test is completed in a small fraction of a second, to very low speeds at which a test may take hours or days to complete.

For commercial testing perhaps the most useful and comprehensive work on this subject is that carried out by Jones and Moore,[1] for the American Society for Testing Materials. These investigators studied the effect of rate of straining, within commercial testing limits, on the tensile properties of steel and of a number of non-ferrous metals and alloys, including two magnesium alloys, Dowmetals " J " and " H " (equivalent to Elektron AZM and the old Elektron AZG*). The conclusions reached from this work were that proof stress increased or remained unchanged with increase in rate of straining for all the materials tested except the magnesium alloys, which gave decreasing values; for ultimate stress, increases in values with increasing rate of straining were obtained for all the materials except the magnesium alloys, for which a decrease was shown in a graph of the results, although this was not stated as being significant or characteristic but association with flaws in the material was mentioned. In a discussion on this paper it was stated by H. W Schmidt,[2] of the Dow Chemical Company, that he had found that speed had no serious effect on the ultimate stress and elongation of Dowmetals " J " and " H-HT."

The effect of rate of loading on magnesium alloy extrusions (Elektron AM.503*) has also been studied by Buchmann[3] who found that this material behaved in the same way as most other materials, i.e., ultimate stress increased with increases in rate of loading. It appeared, therefore, that different magnesium alloys, or forms of alloys, were likely to behave in different ways when subject to variations in rates of loading when tensile testing. In view of this and in connection with a general standardisation of testing procedure it was therefore decided that the effect of rate of loading should be investigated.

* Nominal Compositions are: Elektron AZM—Mg + 6% Al, 1% Zn, 0·3% Mn.
Elektron AZG—Mg + 6% Al, 3% Zn, 0·3% Mn.
Elektron AM503—Mg. + 1·5% Mn.

Experimental

(*a*) *Apparatus and equipment.*

Two tensile testing machines were used for this work; they were :—

1. A 5-ton Denison tensile testing machine. This machine is gear operated from a ¾ h.p. Squirrel cage type A.C. motor. It has four fixed straining speeds, namely 0·1 in., 0·2 in., 0·4 in. and 0·8 in. per minute.

2. A 10-ton Dension universal testing machine. This machine is hydraulically operated and has an unloaded ram speed of from 0 in. to 6 in. per minute.

The weighing systems of both these machines are of the self-indicating type and completely separate from the straining systems.

(*b*) *Methods.*

Tests were made at each of the fixed speeds on the 5-ton Denison machine and at unloaded ram speeds of 1 in., 2 in., 3 in., 4 in., 5 in. and 6 in. per minute on the 10-ton machine. In addition to this, single tests were made on Elektron AM.503 sheet specimens at the slowest and fastest possible speeds on the 10-ton machine. Six test bars in each of the following alloys were tested at each speed :—

		Approximate Grain Size mm.
1.	Elektron A.8* .. As cast	0·10
2.	" A.8* .. Solution treated	0·10
3.	" AZ.91 .. As cast	0·10
4.	" AZ.91* .. Fully heat-treated, 2 sets :— (*a*) Well heat-treated; (*b*) Imperfectly heat treated	0·10
5.	" AM.503 .. As cast	2·0 to 4·0
6.	" AZM. .. ½ in. diameter extrusion	0·015
7.	" AM.503 .. 20 gauge sheet	0·015
8.	" AM.503 .. 14 " "	0·015
9.	" AM.537* .. 14 " "	0·005

* Nominal compositions are: Elektron A.8: Mg + 8% Al, 0·4% Zn, 0·3% Mn.
Elektron AZ.91: Mg + 9·5% Al, 0·4% Zn, 0·3% Mn.
Elektron AM.537: Mg + 2% Mn, 0·4% Ce.

The approximate grain sizes of the materials tested are given as they may have a bearing on the results. The grain size of the as-cast Elektron AM.503 varies with the order of casting, the first bars cast being coarser and the last finer.

The bars for each group of tests (60 tests in each group) were obtained for Elektron A.8 and AZ.91 from single melts of each alloy; for Elektron AZM from six similar

extrusions 6 ft. in length, one test bar from each extrusion being tested at each speed; for as-cast AM.503 from six separate melts all made up from the same ingots, each melt yielding 10 D.T.D. bars. The order of casting for AM.503 was noted and one bar from the corresponding position in each melt was tested at the same speed. For AM.503 and AM.537 sheets test specimens were taken from adjacent transverse positions in single sheets. All the bars for each group of tests on heat treated material were heat-treated at the same time. The dimensions of the test bars were :—

1. For the cast and extruded material, 0·564 in. diameter × 2 in. gauge length.

2. For the sheet, 0·75 in. wide × sheet thickness × 2 in. gauge length.

Ultimate stress and elongation only were determined. Proof stress was not included because of the difficulties of determining this, with the extensometers available, at the higher speeds; also it was considered unnecessary, since by the present methods of testing at Magnesium Elektron, Ltd., the speed of testing to proof stress is not subject to great variations Before starting these tests some consideration was given to the method to be used as a basis for the assessment of testing speeds. Jones and Moore[1] measured the rate of straining of the specimen itself by special strain gauges and in general this is the most widely used method. Buchmann,[3] however, measured rate of loading which is in conformity with German specification D.I.N. 1605 requirements.

The extensometers available here (Lindley, Gerard and Lambs roller) were not suitable for the strain rate method on the higher speeds proposed to be used in the tests. Other approximate assessments of strain rate can be made by measuring the movements of the cross head and straining mechanism or by calculation from the elongation of the test piece. Neither of these methods however gives complete information about the strain rate variations which may occur in the test. Calculating from the elongation of the test does not allow for differences in straining rates which are likely to occur in the periods up to and after the maximum loads. It is considered that the important and decisive period is that up to the maximum load; after the maximum load has been reached the straining rate may remain fairly constant or increase rapidly according to the nature of the material being tested. So far as measuring the movement of cross head and straining mechanism is concerned allowances have to be made for movement of the whole test set up (machine, grips, test piece, etc.) and this is likely to show considerable variation even when similar test pieces are being pulled.

It might also be mentioned that there is a considerable difference between the nominal or unloaded speeds and the actual speeds under load during the test. This is also due to movement of the whole test set-up, to inertia effects, and, particularly in the case of the hydraulic machine, to the resistance of the test piece and the mechanism of the control system.

Measuring the rate of loading also presents some difficulties in that even up to the maximum load the load is not applied at a constant rate for any one setting but at a rate which varies according to the elastic and plastic characteristics of the material being tested. Taking all these things into consideration it was finally decided that an average rate of loading calculated from the time to reach maximum load would give the most satisfactory conception of the speed of testing and this method was therefore adopted.

TABLE I.

Average results of tests made at different testing speeds on as-cast and heat-treated Elektron Casting Alloys. All test bar dimensions 0·564 in. dia. × 2 in. gauge length.

Alloy and Condition	5 ton Denison Machine				10 ton Denison Machine				Approx. minimum and maximum testing speed T/SI per minute	
	Nominal Speed in./min.	Time for maximum load Seconds	Ultimate Stress T/SI	% Elong. on 2 in.	Nominal Speed in./min.	Time for maximum load Seconds	Ultimate Stress T/SI	% Elong. on 2 in.	Minimum	Maximum
Elektron A.8, as-Cast ..	0·1	218	9·9	4·3	1	197	10·1	4·8	3	90
	0·2	112	9·9	4·2	2	35	10·5	4·0		
	0·4	62	10·1	4·3	3	18	10·3	3·8		
	0·8	32	9·8	4·3	4	11	10·1	4·3		
					5	9	10·2	4·5		
					6	7	10·2	3·9		
Elektron A.8, Solution Treated	0·1	485	16·7	14·0	1	592	17·0	14·8	2	75
	0·2	244	16·6	13·3	2	69	16·8	15·3		
	0·4	123	16·7	14·1	3	37	16·5	14·7		
	0·8	67	16·8	14·7	4	23	16·5	14·3		
	—	—	—	—	5	17	16·2	13·4		
	—	—	—	—	6	13	16·3	14·6		
Elektron AZ.91, as Cast	0·1	211	9·5	2·0	1	40	9·5	2·0	3	115
	0·2	104	9·4	1·5	2	15	9·3	2·0		
	0·4	55	9·3	1·5	3	10	8·7	1·5		
	0·8	27	9·2	1·5	4	8	9·2	2·0		
	—	—	—	—	5	6	8·8	2·0		
	—	—	—	—	6	4	8·7	1·5		
Elektron AZ.91, fully heat-treated (Well heat-treated)	0·1	320	17·1	3·5	1	21	16·6	3·0	2	180
	0·2	154	16·7	4·0	2	13	16·6	3·0		
	0·4	81	16·5	3·5	3	10	16·7	4·0		
	0·8	39	16·5	3·5	4	8	16·1	3·0		
	—	—	—	—	5	7	16·5	3·0		
	—	—	—	—	6	5	16·5	3·5		
Elektron AZ.91, fully heat-treated (Imperfectly heat-treated)	0·1	183	12·6	2·2	1	263	12·8	1·9	3	125
	0·2	89	12·3	2·2	2	40	13·1	1·9		
	0·4	49	12·8	1·8	3	19	12·5	2·1		
	0·8	25	12·3	1·7	4	11	12·6	2·6		
	—	—	—	—	5	8	11·9	1·6		
	—	—	—	—	6	6	42·3	1·9		
Elektron AM.503, as Cast	0·1	327	6·6	6·6	1	28	5·8	6·6	1	65
	0·2	164	6·6	6·4	2	16	5·9	6·8		
	0·4	85	6·7	7·0	3	9	5·9	6·8		
	0·8	43	7·0	7·8	4	8	6·2	7·0		
	—	—	—	—	5	7	6·5	5·9		
	—	—	—	—	6	6	6·2	6·7		

The above values are the average of at least four results.

As each test was made the time in seconds for the maximum load to be reached was observed by means of a stop watch and recorded. The times to reach maximum loads varied from 4 seconds to 600 seconds, excluding the time of 8 hours for the single test on Elektron AM.503 sheet. These rates are similar to those examined by Jones and Moore[1] but cannot be compared with results obtained at the ultra high speeds which can be obtained by impact tension testing. Also, while these variations have been obtained on commercial testing machines it is not likely that under ordinary conditions of testing such extremes would be used; at Magnesium Elektron, Ltd., the usual speeds are :—

1. On the 5-ton machine : Proof stress at the fixed nominal speeds of 0·2 in. and 0·4 in. per minute, and ultimate stress at the fixed nominal speed of 0·8 in. per minute.

2. On the 10-ton machine : Proof stress at the unloaded ram speeds of $1\frac{1}{2}$ in. to 2 in. per minute (loaded ram speed of approximately 0·2 in. to 0·4 in. per minute) and ultimate stress at unloaded ram speed of $2\frac{1}{2}$ in. to $3\frac{1}{4}$ in. per minute (loaded ram speed of approximately 0·8 in. to 1·0 in. per minute).

(*c*) *Results.*

The average results for each testing speed are given in Tables 1 and 2. The results for the single tests at the fastest and slowest possible testing speeds (normal testing) are given in Table 3. The average, and maximum and minimum ultimate stress and elongation values for each speed of testing, plotted against average time for maximum load are also given in Figures 1 to 5. Figure 3 also shows the relation between sequence of test bar casting and ultimate stress of as-cast Elektron AM.503.

(*d*) *Interpretation.*

It is evident from the graphs that the materials under test, or the test bars used, have not responded in the same way to the different rates of loading, and also that even at one rate of loading some of the results have shown considerable scatter. This scatter, which is shown in all elongation values and in the ultimate stress values for solution-treated A.8 and fully heat-treated AZ.91 indicates that no single value for any one of these properties at any one speed can be fixed, but that they should be considered as within a band. Each group of tests has therefore been examined separately and allowances have been made for the scatter so that even though the plot of average values may show a slight upward or downward trend, if this is not confirmed after a consideration of the scatter limits, such a trend is not considered significant.

The examinations have shown that for :—

1. *As-cast Elektron A.8* : The effect of rate of loading within the limits of 3 to 90 T/SI per minute is negligible both for ultimate stress and elongation.

2. *Solution Treated Elektron A.8* : The ultimate stress values show a slight downward trend with increased rate of loading, falling from 17·0 T/SI at the lowest rate (2 T/SI per minute) to 16·3 T/SI (average values) at the highest rate of loading (75 T/SI per minute). Elongation does not appear to be affected.

3. *As-cast Elektron AZ 91* : The ultimate stress values show a slight downward trend, from 9·5 T/SI to 8/7 T/SI, with increased rate of loading within the range 3 to 115 T/SI per minute (Table I).

It is interesting to note that a few special tests on as-cast Elektron AZ.91 have shown that at higher rates of loading, which are not likely to be encountered in ordinary commercial testing practice, the downward trend of ultimate stress becomes well-defined, average values being 8·0 T/SI at 178 T/SI per minute and 7·1 T/SI at 237 T/SI per minute. The test results are shown in Table IV, and average values have been included in Fig. 2 for comparison purposes.

4. *Fully heat-treated Elektron AZ.91* : Within the limits of 2 to 180 T/SI per min. the results are similar to those for the alloy in the as-cast condition. The results show the superiority of well heat-treated AZ.91 over that of the same alloy imperfectly heat-treated.

5. *As cast Elektron AM.503* : The test bars were not of uniform properties : each set of 10 bars showed the

TABLE II.

Average results of tests made at different testing speeds on wrought Elektron Alloys.
Test Bar Dimensions :—Extruded Bar, 0·564 in. diameter × 2 in. gauge length.
Sheet 0·75 in. wide × sheet thickness × 2 in. gauge length.

Alloy and Condition	5 ton Denison Machine				10 ton Denison Machine				Approx. minimum and maximum testing speed T/SI per minute	
	Nominal Speed in./min.	Time for maximum load Seconds	Ultimate Stress T/SI	% Elong. on 2 in.	Nominal Speed in./min.	Time for maximum load Seconds	Ultimate Stress T/SI	% Elong. on 2 in.	Minimum	Maximum
Extruded Elektron AZM. ($\frac{3}{4}$ in. dia. bar)	0·1	502	19·7	20·2	1	602	19·9	20·3	2	75
	0·2	231	19·6	20·7	2	89	19·5	19·7		
	0·4	136	19·5	21·0	3	44	19·6	20·0		
	0·8	69	19·5	19·8	4	29	19·6	18·8		
	—	—	—	—	5	19	19·4	19·7		
	—	—	—	—	6	15	19·3	19·5		
Elektron AM.503 Sheet 20 s.w.g.	0·1	257	15·4	11·3	1	160	15·5	11·3	3	165
	0·2	120	15·8	10·7	2	30	16·1	10·3		
	0·4	63	16·1	11·8	3	18	16·3	11·8		
	0·8	31	16·5	13·3	4	11	16·5	10·8		
	—	—	—	—	5	9	16·6	11·3		
	—	—	—	—	6	6	16·7	11·1		
Elektron AM.503 Sheet 14 s.w.g.	0·1	198	15·2	5·8	1	169	15·1	6·3	5	200
	0·2	98	15·5	6·3	2	30	15·9	6·1		
	0·4	48	15·7	5·4	3	11	16·2	5·9		
	0·8	25	16·1	5·8	4	8	16·5	6·7		
	—	—	—	—	5	6	16·5	5·8		
	—	—	—	—	6	5	16·7	6·5		
Elektron AM.537 Sheet 14 s.w.g. *W*	0·1	311	16·0	22·2	1	118	16·2	18·8	3	150
	0·2	143	16·2	21·0	2	34	16·9	17·9		
	0·4	75	16·6	19·0	3	19	17·3	16·6		
	0·8	35	16·7	17·4	4	12	17·6	17·7		
	—	—	—	—	5	10	17·7	17·7		
	—	—	—	—	6	7	17·6	17·1		

The above values are the average of at least four results.

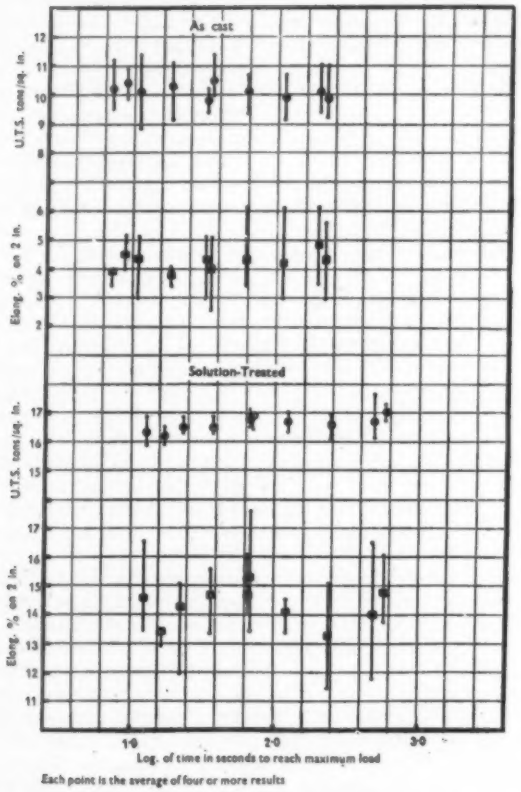


Fig. 1.—Graphs showing effect of average rate of loading on ultimate tensile stress and elongation of as-cast and solution-treated Elektron A.8. The vertical lines indicate scatter of individual results.

same general connection between sequence of casting and strength, the first bars cast being of lower strength and the last bars of higher strength (the ultimate stress

TABLE III.

Results of single tests made at the fastest and the slowest possible testing speeds on 16 s.w.g. Elektron AM.503 Sheet. 10-ton Denison machine.

Time to Fracture	Ultimate Stress T/SI	% Elongation on 2 in.
7 seconds	17·5	10·0
8 hours	14·6	14·5

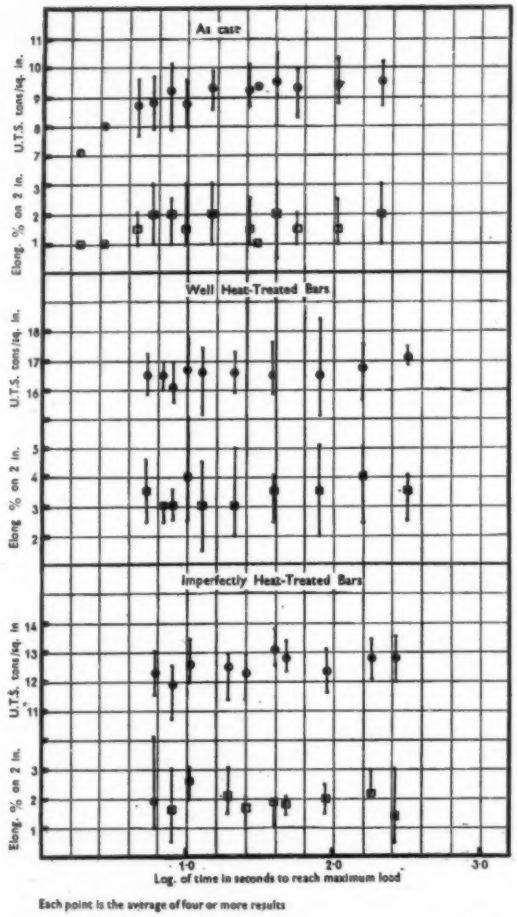


Fig. 2.—Graphs showing effect of average rate of loading on ultimate tensile stress and elongation of as-cast and fully heat-treated Elektron AZ.91. The vertical lines indicate scatter of individual results.

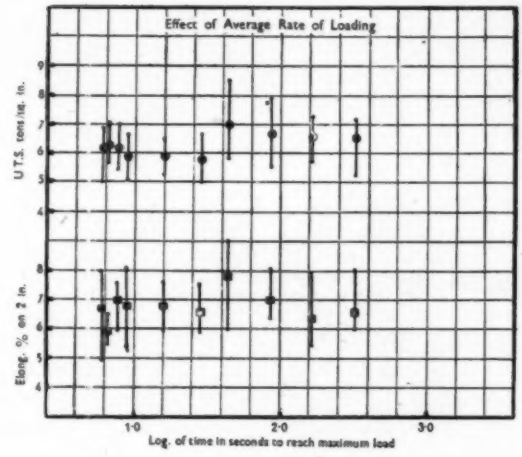
values are shown plotted against sequence of casting in Fig. 3). One set of bars showed a difference of 1·9 T/SI between the first and last bars cast. In view of this non-uniformity of test bar properties no definite conclusions have been drawn from these tests although the indica-

TABLE IV.

Results of Special Speed Effect Tests on As-Cast Elektron AZ.91.
Tests Made on the 10-ton Denison Universal Testing Machine. Test Bar 0·25 sq. in. in Cross Section Area.

Melt No.	One inch per minute.				Six inch per minute.				Eleven inch per minute.			
	Bar No.	U.T.S. T/SI.	Elong. % on 2 in.	Time to break. Seconds.	Bar No.	U.T.S. T/SI	Elong. % on 2 in.	Time to break. Seconds.	Bar No.	U.T.S. T/SI.	Elong. % on 2 in	Time to break. Seconds.
"A"	4	8·2	0*	18·1	1	7·1	0·5*	2·6	2	6·5	0·5*	1·7
	7	8·0	1·0	19·0	3	8·4	1·5	3·0	—	—	—	—
	—	—	—	—	5	8·1	1·5	2·4	—	—	—	—
"B"	24	9·8	2·0	63·0	21	7·8	0·5*	2·5	22	7·4	0*	1·9
	26	10·0	2·0	26·0	23	8·8	1·0*	2·6	27	8·4	2·0	1·9
"C"	4	9·4	0*	29·5	1	7·6	0*	3·6	2	7·2	0*	1·7
	6	9·1	0·5*	24·0	5	7·5	0*	2·7	3†	6·5	0·5	1·4
"D"	4	9·5	2·0	29·0	1	8·6	2·5	2·5	2	7·4	1·5	1·9
	6†	10·0	1·5	28·5	—	—	—	—	3	5·6	2·0	1·8
	—	—	—	—	—	—	—	—	5	7·8	2·0	1·8
Average	—	9·3	1·0	29·6	—	8·0	1·0	2·7	—	7·1	1·0	1·8

* Broke outside the gauge length. † C3, D6:—Dia. 0·505 in., Area 0·200 sq. in.



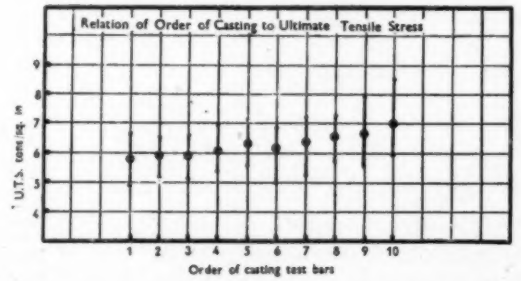


Fig. 3.—Graphs showing effect of average rate of loading on ultimate tensile stress and elongation of as-cast Elektron AM.503 and the relation of the order of casting the bars to the ultimate stress. The vertical lines indicate the scatter of individual results.

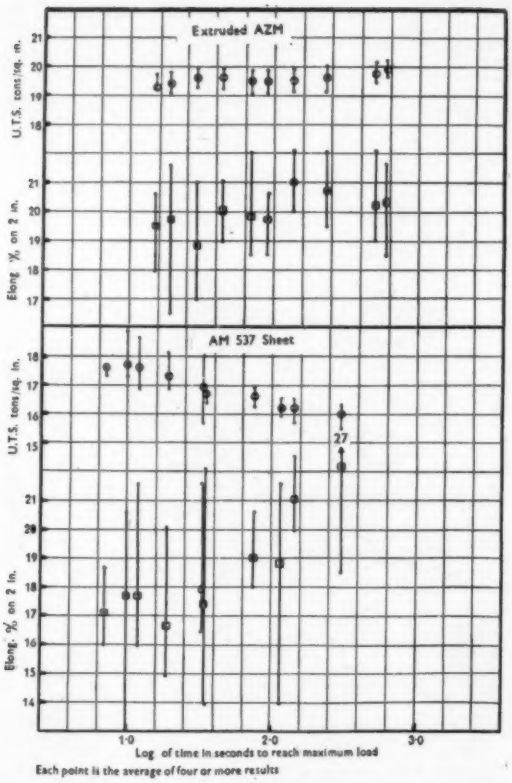


Fig. 4.—Graphs showing effect of average rate of loading on ultimate tensile stress and elongation of extruded Elektron AZM. (¾ in. dia.) and Elektron AM.537 sheet (14 gauge). The vertical lines indicate the scatter of the individual results. Sheet tests at right angles to the direction of rolling.

tions are that rate of loading has no effect on ultimate stress and elongation. The relation between strength and sequence of casting is noteworthy and should be borne in mind when making castings in this alloy. The casting temperatures were : 780° C. at the start and 740° C. at the finish of the pour.

6. *Extruded Elektron AZM :* Within the limits of 2 and 75 T/SI per minute the ultimate stress values remain fairly constant at all but the lowest rates of loading for which a slight increase is shown. The elongation values show a slight downward trend with increased rate of loading.

7. *Elektron AM.503 Sheet :* Within the limits of 5 to 200 T/SI per minute for 14 gauge sheet and 3 to 165 T/SI per minute for the 20 gauge sheet, both these sheets show the same definite upward trend for ultimate stress with increased rate of loading ; elongation values remain constant within the scatter bands. This effect on ultimate stress is confirmed by the single tests made at the fastest (150 T/SI per minute) and slowest (0·03 T/SI per minute) possible rates of loading, the former giving a result 2·9 T/SI higher than the latter. These tests also gave different elongation values but they both lie within the scatter bands obtained in the main tests and cannot therefore by themselves be regarded as significant, although from the tests on AM.537 sheet it it does appear that elongation values are affected by rate of loading.

8. *Elektron AM.537 Sheet :* Within the limits of 3 to 150 T/SI per minute the ultimate stress values show the same definite upward trend with increased rate of loading as those for AM.503 sheet. Elongation values show the reverse effect and fall with increased rate of loading.

Summarising these values it is seen that they may be divided into two classes :—

Class I—Being those from round test bars prepared from cast aluminium and manganese containing alloys, and a wrought aluminium-containing alloy all of which are insensitive or only slightly sensitive to changes in rate of loading ; and

Class II—Those from flat test bars prepared from rolled manganese and manganese plus cerium—containing alloy sheet which are very sensitive to changes in rate of loading.

Conclusions

The conclusions to be drawn from this work are that :—

Within the range examined different magnesium alloys or forms of alloys (e.g., cast, extruded or rolled) behave in different ways when subject to variations in rates of loading when tensile testing. The Elektron alloy A.8, as cast and solution treated ; AZ.91, cast and fully heat-treated, ; AM.503, as cast ; and AZM., extruded, are insensitive or sensitive only to a negligible degree to

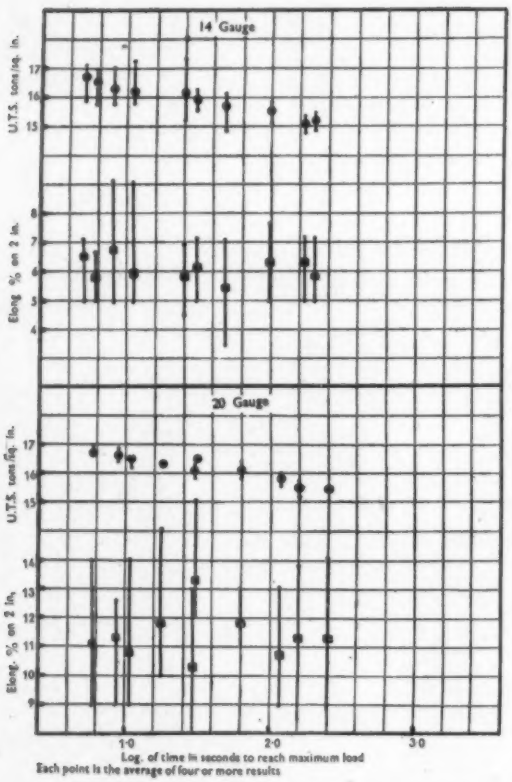


Fig. 5.—Graphs showing effect of average rate of loading on ultimate tensile stress and elongation of Elektron AM.503 sheet (14 and 20 gauge). The vertical lines indicate the scatter of individual results. All tests at right angles to the direction of rolling.

variations in rate of loading while the Elektron alloys AM.503 and AM.537, in sheet form, are sensitive to a high degree.

Recommendations

The fact that some magnesium alloys in certain conditions are very sensitive to changes in rate of loading makes it desirable that testing procedure should be standardised so that proper comparisons can be made and it is recommended that speeds of tensile testing, for all magnesium alloys, should be fixed within reasonably close limits, say 0·1 in. to 0·5 in. per minute for proof stress and 0·75 in. to 1·5 in. per minute (loaded ram speeds) for ultimate stress. The actual speed of testing should be given when test results are being published.

REFERENCES.

1 An Investigation of the Effect of Rate of Strain on the Results of Tension Tests of Metals. Jones and Moore, *Proc. A.S.T.M.*, **40**, 1940, page 610.

2 Statement by H. W. Schmidt in discussion on above paper, *Proc. A.S.T.M.*, **40**, 1940, page 637.

3 "Mechanical Properties of Magnesium Alloys." Chapter 5 of "The Technology of Magnesium and Its Alloys" (F. A. Hughes, London, 1940).

4 "The Mechanical Properties of Some Metals and Alloys Broken at Ultra High Speeds." D. W. Ginns, *J. Inst. Metals*, 1937, **61** (2), 61.

5 "Dynamic Tensile Properties and Stress-strain Diagrams of Some Constructional Materials." G. Welter and Morski, *J. Inst. Metals*, 1940, **66**, 97.

6 "The Yielding Phenomenon of Metals," G. Welter, METALLURGIA, 1945, **31**, 144, 207, 263, 309, **32**, 31, 80.

THE Ministry of Supply announces, it is officially reported that so far stocks of tin metal amounting to 17,000 tons have been discovered in Malaya.

Personal

Mr. G. WESLEY AUSTIN, O.B.E., M.Sc., has been appointed Goldsmiths Professor of Metallurgy in the University of Cambridge.

Dr. H. J. GOUGH, F.R.S., has relinquished the post of Chief Scientific Officer to the Ministry of Supply and is joining Messrs. Lever Brothers and Unilever, Ltd., as Engineer-in-Chief.

Mr. W. E. PRYTHERCH, M.Sc., F.R.Ae.S., has resigned his position as Technical Director of High Duty Alloys, Ltd. We understand that Mr. Prytherch intends to act as an independent Research Consultant, and that he will act in that capacity for the group of companies being formed by Col. W. C. Devereux.

Sir WILLIAM LARKE, K.B.E., has been released by the Minister of Supply from his post of Controller of Non-Ferrous Mineral Development. Correspondence should now be addressed to the Non-Ferrous Mineral Development Section, Raw Materials Department, Ministry of Supply, Selection Trust Buildings, Masons Avenue, Coleman Street, London, E.C.2.

Dr. J. H. CHESTERS of the Central Research Department of The United Steel Companies Ltd. has just been awarded the Degree of Doctor of Technical Science by the University of Sheffield.

Dr. Chesters graduated from Sheffield University (Hons. Physics) in 1928 and obtained his Ph.D. in 1931 as a result of researches on induction furnace linings. He was then a Metropolitan-Vickers Scholar and afterwards went with a Robert Blair Fellowship to Berlin, and later as a Common-wealth Fellow to America in order to continue his researches on refractories.

It will be remembered that Dr. Chesters book entitled "Steel plant Refractories" was published by The United Steel Companies Ltd. in January of this year, and has already been hailed as the standard text-book on the subject. He is now engaged on work in the field of open-hearth furnace design. The research is of such a nature as to constitute a new approach to the problem of finding suitable refractories to meet the fast working conditions of the furnace of the future.

Kent Alloys Ltd.

FOLLOWING a recommendation by the Board of Messrs. Short Brothers (Rochester and Bedford) Ltd., the Minister of Supply and Aircraft Production has agreed to the sale of Kent Alloys Ltd. to Messrs. Dawnay, Day and Co., Ltd., who have purchased the entire Share Capital.

The policy of the Company remains unchanged and, under the General Managership of Mr. F. H. Hoult, the Company will continue its business of manufacturing and machining high grade aluminium, magnesium and heavy non-ferrous alloy castings.

The Sir William J. Larke Medal

THE winner of the above medal and award for 1945 is Mr. W. K. B. Marshall, B.Eng., of The Aluminium Plant and Vessel Co., Ltd. The presentation was made at a recent meeting of the Institute of Welding, held at the Institution of Civil Engineers, at which were present the Presidents of the Belgian, French and Dutch Welding Societies. The paper which secured this award, entitled "The Fabrication of Aircraft Fuel Tanks in Aluminium Alloy Containing 3% Magnesium," was presented by Mr. Marshall at the meeting.

Radio Frequency Heating

Various adaptations of radio-frequency heating were demonstrated at a recent exhibition in London at which the primary aim was to explain what it is and how it works and what it can do for industry. These notes direct attention to its application to the treatment of ferro-magnetic materials.

THE use of radio during the war produced phenomenal results and its adaptation to peace-time requirements will revolutionise those industries to which it can be linked, particularly where heating by radio-frequency is involved. Evidence of this was given recently at an exhibition of Redifon radio-heating held at Dorland Hall, London, by Rediffusion Ltd. The method developed provides a means of generating heat directly in the material under treatment, as distinct from the usual method employed in industry, which depends upon the conduction or radiation of heat energy from an external source into the material being processed.

The new method not only speeds up the process, but by its uniformity ensures a better quality in the finished article or material. It means that, in applying the method, no weak spots result, either in jointing, bonding or moulding, whilst drying, melting, annealing and case-hardening are carried out with complete thoroughness. Many examples of this method of heating were demonstrated at the exhibition ; it was shown, for instance, that a piece of wood 2 in. thick, which normally takes 3 hours to heat, could be heated throughout in 40 seconds ; and that the moulding of plastics is speeded up from twice to ten times as fast, the intense application of heat ensuring that the curing is uniform throughout, leaving no weakening core. Attention was directed to the wide range of building materials and components capable of being effectively processed by the method demonstrated. But radio heating applied to metal is as rapid and as accurate as with any other materials and it is this application with which many readers will be especially interested.

The application of radio-heating in the plastic, rubber, timber, chemical and other industries, in which the materials are either non-conductors or very poor conductors of heat, differs radically from that required in heating metals. The method adopted for applying radio heat to conductors, principally steel, is by induction or eddy-current heating.

Induction heating is applied to annealing, case-hardening and to melting of steels and other metals, and the wider acceptance and more general use of this form of heating, during recent years, has caused equipment for the process to be installed in a large number of manufacturing and metal processing plants.

From an engineering point of view there are three factors which should be taken into consideration in deciding whether heating by high-frequency induction is applicable. One of the factors concerns the localisation of heat to the surface of the metal to be treated, a phenomenon inherent in high-frequency induction heating. A second factor is the localisation of heat to a particular part of the metal component. These two factors arise especially in the surface hardening of a restricted section of a shaft required to possess good wearing characteristics and yet retain the toughness of core necessary to withstand torsional stress. The third factor concerns the speed of heating desired to reduce oxidation, scaling and decarburisation, the extent of which are functions of time as well as of temperature.

Sir John Anderson and Sir Wavell Wakefield examining a Redifon R.H.4 radio-heater applied to profile hardening the teeth of steel gear-wheels.

In addition to surface hardening, these factors arise when considering annealing problems. Very few components involve surface annealing, although threading or tapping may be so treated, but the annealing of restricted areas on a steel component is a fairly common application of induction heating. Where rapid heating is desired, as when annealing steel tubing, strip and wire, the use of induction heating may be indicated, not only to induce oxidation but where space is at a premium and does not permit what is frequently regarded as the more conventional type of equipment.

It is noteworthy that induction hardened steels show a greater hardness than similar steels hardened by conventional means. This fact has been verified by many workers and an explanation has long been sought. It has been suggested that since hardness in steel has been shown to be a function of the solution and diffusion of the iron carbide into and throughout the steel, the carbide being finely divided, any increase in hardness must be accomplished by a more complete solution and diffusion than is obtained by conventional heating methods.

Induction heating is produced by a coil, nearly always water-cooled, surrounding the metal component. When alternating currents flow in the coil, similar currents are induced in the component, which heats up. At radio-frequencies these currents do not penetrate into the metal more than a few thousandths of an inch, deeper heating being due to conduction from the hot outer layer. Thus, it is possible to induce very heavy currents and to promote extremely rapid heating of the surface layers, to hardening temperatures, before conduction has an appreciable effect.

Since the fundamental requirement of induction heating is alternating current, such heating can be accomplished with any frequency from 50 cycles up to millions of cycles per second. There are several types of induction heating equipment, and there is a direct relation between the type of equipment, its practical frequency range, and the heating job it is best suited to perform. Motor generators, for instance, are used for frequencies up to 12,000 cycles per second. These are well adapted to deep heating of ferro-magnetic materials. Spark gap units are used for frequencies between 20,000 and 300,000 cycles per second. These are suitable for general heat treatment such as melting, deep surface hardening and general purpose brazing. The newest type of induction heating unit is the vacuum unit adapted to frequencies from 350,000 to 100,000,000 cycles per second. For induction heating purposes the range most widely used is 350,000 to 15,000,000.

The two latter types are used for thin case hardening in which the case is of the order of 0·0001 in. (2·5μ) thick. This case is given to suitable steels without scaling, warping or destruction of the previous heat treatment benefits developed in the steel just beneath the surface. The need of high frequency is especially advantageous with light-weight aircraft engine parts and many other components necessitating precise and thin surface hardening with no hazard to the structure and properties of the underlying metal. Since the heat treatment by the vacuum tube unit is accomplished in little more than a second, scaling is avoided even in ordinary atmosphere.

Several generating units were exhibited by Rediffusion Ltd., the largest being model R.H.4, which produces 25 kw. It was used to demonstrate a modified form of the process by profile hardening the teeth of a typical steel gear wheel. Smaller equipment, a 5 kw. unit, R.H.31, was applied to the hardening of a gear 1¼ in. diameter ; this equipment was fitted with an automatic quench coil. A 2 kw. unit, fitted with a heating coil, was used to demonstrate the hardening of O.B.A. taps and the surface hardening of ¼ in. steel rod. These demonstrations, besides being informative, have promoted great interest in representatives from the many industries in which this form of heating can be profitably applied.

The ready adaptation of this relatively new form of heating requires a knowledge of the various inherent characteristics and behaviour of high frequency energy. For instance, especially in applying it to ferro-magnetic materials, the proper frequency, time cycles, and inductor design, and their relationship to the shape and dimensions of the component to be treated are very important. Rediffusion Ltd. invite discussion on possible adaptation of radio-frequency heating, especially in connection with mass-produced components, both technical and economic aspects will be considered.

An Electronic Material Analytical Comparator

A SIMPLE analytical comparator, of robust but sensitive design, has been developed for the rapid and accurate comparison of the physical and chemical constituents of ferrous and non-ferrous materials. It is claimed that, by means of this comparator, any number of materials may be checked against a standard with infallible accuracy and at greater speed than by any other known method.

The Cornelius electronic material analytical comparator.

The principle on which the comparator functions involves the use of high frequency radio circuits which are modulated by the various elements included in the materials to be compared. The variations in the high frequency circuits are amplified and their amplitudes limited in such a manner as to reduce any variations likely to be caused by extraneous effects, such as mains voltage variations or even broadcast radio waves that could possibly be picked up by the apparatus. The final frequency modulated current is then demodulated in a special circuit and the rectified current is measured by an accurate sensitive meter of robust design.

The scale length of the meter employed is approximately 4 in., and it is conveniently marked in equal divisions. The indicating needle is instantaneous in operation and does not vibrate at the indicating position, but stops at the end of its stroke permitting the rapid reading of its position on the scale. The needle deflection indicates the similarity between the standard sample and the piece under test. Tolerances can be given between which acceptance is made. Various degrees of sensitivity are allowed for the design which permit very small variations to be exaggerated for one or a plurality of constituent elements, whilst others, of less importance, are not accentuated at all and are therefore not effective in the readings obtained.

In addition to analytical work various test holders used with the instrument can be applied to many other tests, such as detecting flaws—cracks, holes, etc.—in samples, while others can be designed to operate as sizing indicators on material that is comparatively analytically identical. This instrument has already been used in several factories with marked success and has proved a time saver in laboratories.

The instrument, for which the sole distributors and licensees are Stuart Davis Ltd., Machine Tool Equipment Engineers, 1, Laurence Pountney Hill, London, E.C.4, is entirely self-contained and reasonably light and portable ; it can be supplied either with a standard test plug or a special plug to order, for use with A.C. mains operating 40 to 100 cycles, 200, 220, 250 volts, or for battery operation. The casing is carefully screened for radio interference and the operator is perfectly safe from shocks of any kind.

Birmid Industries Ltd.

BIRMABRIGHT LTD. have opened a Marine Department at the London Offices of the Birmid Industries Group—20, Berkeley Square, London, W.1—with the object of providing information and assistance to naval architects and marine engineers who are interested in aluminium alloy as a material for marine construction. The department will be under the superintendence of Lieut. Commander F. Merrett, R.N.R., Retd. Mr. T. C. Scovell, M.I.N.A., has been appointed as Naval Architect.

Rapid Photometric Determination of Copper, Nickel, Manganese and Iron in Aluminium Alloys

By W. Stross

Well known techniques for the photometric determination of copper, nickel and manganese are critically revised and partly modified; in addition, an existing scheme for determining many elements on one weighing is discussed and a modification suggested.

THE literature about the colorimetric and photometric determination of copper, nickel, manganese and iron is very comprehensive. A great variety of methods and of techniques for a large number of special applications have been suggested.[1] A study of the literature dealing with the application of some of these methods to aluminium alloys, e.g. [2, 3, 4, 5, 6], is likely to create the impression that in this field techniques are so well developed that there remains very little scope for further investigation.

When following exactly the lines established in these papers, failures and difficulties were, however, encountered, particularly with certain alloys, and it became evident that the published methods do not cover all ranges of alloys in industrial use. These limitations—stated though not explained in one case[2] and possibly overlooked by the authors in others—would seriously interfere with the practical utilisation of these methods for general speedy production control on a wide range of compositions. Modifications had therefore to be found which—though not establishing any fundamentally new facts—necessitated sufficient experimental work to justify possibly this communication, into which, in addition, some practical details apt to increase simplicity and speed were incorporated.

A. Copper and Nickel

The two mostly used methods of determining these two elements without recurring to chemical separations—i.e. the formation of the colloidal coloured complex with sodium diethyl dithiocarbamate for copper, and of the oxidised soluble complex with dimethylglyoxime for nickel—have two features in common: (*a*) the colour is produced at ammoniacal reaction, thus necessitating the presence of citrate or other precautions to keep aluminium and other elements in solution; (*b*) both metals can very easily be determined in aliquots of one and the same metal solution, thus necessitating one weighing only. Copper and nickel will therefore be treated together.

(1) Solutions Used:

(*a*) 15% sodium hydroxide solution (15 g solid caustic soda plus 100 ml water).

(*b*) Citric acid solution: dissolve 1 kilo citric acid crystals (AR or BP) in water, make up to 2 litres.

(*c*) A 2% solution of gum arabic (the commercial "best" quality or "Gum Acaciae elect. powder") is clarified by filtration (which tends to slow down considerably—accelerators and frequent changing of the filter are helpful) or, preferably, by centrifuging. If not used within a day or two for preparing solution (*d*) the growth of microbes must be prevented e.g. by adding some chloroform (5 ml per litre).*

(*d*) "Mixture" for copper: To 560 ml of the citric acid solution (*b*) add 390 ml of water and then, cautiously whilst stirring, 850 ml of 17 N Ammonia, followed by 200 ml of the clarified gum solution (*c*). We find that the strength of the commercial "0·88" Ammonia varies considerably; although the quantity used is not critical, we prefer to check its strength and to add a defined quantity, i.e. the amount equivalent to 850 ml N 17, using correspondingly less or more water to bring the final volume of the "mixture" to 2 litres. This mixture, in which the gum is not subject to microbial decomposition, is stable over a period of about a fortnight.

(*e*) 1% solution of sodium diethyl dithiocarbamate (keeps only a few days).

(*f*) "D.M.G. Mixture": To 560 ml of the citric solution (*a*) add 800 ml of water and 640 ml 17N Ammonia in which 0·8 g dimethylglyoxime had been dissolved. Allow for variations of the strength of the commercial ammonia as sub (*d*). This mixture keeps up to a fortnight. We prefer to prepare it from stock solutions about twice per week.

(*g*) N/10 Iodine solution.

(2) Procedure:

(*a*) *Processing.* Attack 200 mg of alloy in 250 ml beakers with 20 ml of the caustic soda solution. Cover with watch glass. If necessary, warm *gently* to speed up reaction. When the violent attack has ceased, wash down watch glass and walls. Cover with watch glass again and boil (moderately only, to avoid considerable loss of water) for not more than 5 minutes. Wash down watch glass. Add with vigorous shaking 20 ml nitric acid (1 : 1). Dip-pipettes as described previously[8] are very useful for this operation. Under these conditions of dilution and shaking, a clear solution should be obtained after a few seconds. Cover with watch glass again and bring just to the boil to ensure complete solution of copper and nickel. If beakers smaller than 250 ml are used, there is a considerable danger of bumping in this stage. Take off from the hot plate, wash down the watch glass and filter through Whatman

1 For a survey see, e.g. (*a*) F. D. and C. T. Snell, Colorimetric methods of analysis, Vol. 1. New York 1941.
(*b*) Organic Reagents for metals, Hopkin and Williams Ltd., 1943.
(*c*) The B. D. H. Book of Organic Reagents, 1941.

2 Analysis of Aluminium and its Alloys. Publication No. 399 (1941), British Aluminium Company.

3 F. W. Haywood and A. A. R. Wood, Metallurgical Analysis. Hilger Ltd., 1944.

4 E. J. Vaughan. The Use of the Spekker Photoelectric Absorptiometer in Metallurgical Analysis, Monograph, Institute of Chemistry, 1941.

5 E. J. Vaughan. Lecture on further advances in the Use of the Spekker, etc. ibidem 1942.

6 D. E. Phillips and L. L. Edwards, *Metal Industry*, **66** (1945), 409.

* Thymol which is often so useful for this purpose, interferes with the subsequent procedure.

7 W. Stross, *The Analyst*, **67** (1942), 317.

8 W. Stross, ibidem, **69** (1944), 44.

541 filter (11 cm) into a 200 ml measuring flask. The wide necked flasks with two marks as referred to previously[3] are very advantageous for this and also the following operations. Cool and make up to volume.

(*b*) *Copper Determination.* Pipette a suitable aliquot —e.g. 10 ml for alloys with up to 2·2% copper, 5 ml for 2·2 to 5%—into a wide necked 100 ml measuring flask, add (conveniently by dip pipette) 50 ml of the mixture (*d*), make up to mark and colour up by adding 1 ml of the sodium diethyl dithiocarbamate solution.* Mix without much delay.

(*c*) *Nickel Determination.* Pipette a suitable aliquot (10–15 ml for alloys with up to 0·5% nickel, 5 ml for up to 1·8%) into a 50 ml measuring flask, followed by 1 ml of the iodine solution.* Add—conveniently by dip pipette—25 ml of the "D.M.G.-mixture," let stand for at least 1 minute before making up to mark and mixing. Measure, for copper as well as for nickel, the light absorption, e.g. in a 4 cm cell on the Spekker absorptiometer,† using the filament lamp, heat protecting "Calorex" and 601 Ilford Spectral filters,‡ setting the instrument 1·30 "water to water."[4]

TABLE I.

In 100 ml final solution are contained

for Cu determination	B. A. Co. (2)	Haywood & Wood (3)	Phillips & Edwards (6)	Author °	for Ni determination	Vaughan (5)	Phillips & Edwards (6)	Author
mg alloy ..	2·5–50	50–100	5–100	5–10	mg alloy ..	25	5–100	10–30†
grams citric acid	3	5	1·5–12	7	grams citric acid ..	5	1·5–12	7†
ml conc. ammonia ..	7·5	8	15–20	ca 21	ml conc. ammonia..	15	15–20	ca 16†
mg gum arabic ..	25	50	50	100	ml N/10 Iodine ..	5	2·5	2†
mg Carbamate ..	50	20	10	10	mg DMG..	20	20	20†

° The final volume is here 101 ml.
† Actually only ½ of this is used in our routine, as only 50 ml of solution are prepared.

For constructing the calibration graph we use standard alloy samples in preference to solutions of nickel and copper salts[2, 3, 5, 6], although there is hardly any difference for the higher ranges (where smaller aliquots are used). For the lower ranges slight discrepancies between the two ways of calibrating were found which were only partly explained by a series of experiments on synthetic solutions of salts of the various alloying elements. These elements show, in general, very little influence on the copper and nickel extinction (6) so that for the usual commercial alloys allowance need only be made for the presence of more than 2% copper for the purpose of the nickel determination.

(3) Remarks

(*a*) *Attack.* Whilst it is mostly recommended[2, 6] to attack the metal with acids we found that this involves, with certain alloys, the risk of low results through retention of some copper and nickel with the undissolved silicon. This loss is not significant (less than 1% of the total content) in the majority of cases. In some specimens of certain alloys, however (particularly among those with more than 10% silicon), we found this retention in the acid insoluble fraction to be up to 5% of the total. Although this seems to apply only to a minority of these special alloys, we prefer attacking with caustic, followed by nitric acid, as all constituents are thus taken into solution.

With this latter attack it becomes necessary to control the caustic concentration carefully; if weak solutions are used, as recommended by some authors[4, 3] the conversion of the silicon to silica may be incomplete on samples with high silicon content. A partial conversion only, followed by filtration[3] seems a rather unsatisfactory procedure. If unnecessarily strong* caustic, however, is used in glass vessels, or if the boiling is too vigorous, or the time of boiling unduly extended, so much silica is dissolved from the glass, that an objectionable turbidity or even precipitation develops in the final stage. Apart from the influence of the ammonia a mutual flocculation of silica and of the colloidal copper-carbamate complex seems to occur, if both are present in comparatively high concentration, and this cannot be prevented by increasing the amount of gum arabic nor by the use of other colloids (gelatine, gum Ghatti, starch). Clear solutions are, however, invariably obtained if the above instructions are exactly followed and if the hot-plate used is not too hot.

(*b*) *Reagents.* The concentrations obtained in the final solution prepared as recommended above, are compared, in Table I, with those used by other authors.

We find the higher quantities of citric acid and gum arabic advantageous as they ensure slightly greater transparency of the final solutions. The necessity for increasing the ammonia concentration beyond that recommended by several authors[3, 4] has been emphasised by Phillips and Edwards (6) and we confirm this entirely.

It was found possible to incorporate several reagents in one composite solution†, as described below. The advantage of this procedure as to speed and simplicity is obvious; we also found the reproducibility of results to be slightly improved by the use of these "mixtures."

The optimum amount of iodine may vary with different batches of citric acid and it is, therefore, advisable to check it for each batch of reagents, by preparing a series of solutions from one and the same metal with varied quantities of iodine; we use approximately the double of the minimum quantity leading to full colour development. A "blank" has to be made for each iodine concentration and its light absorption must be allowed for.

No strict timing of the interval between preparing and measuring the final solutions is required, due to the comparatively great stability** of the colour, and the influence of temperature is negligible under normal conditions. The calibration graph is reasonably stable provided exactly the same position is given each time to

* A straight 5ml pipette (divided in 1/20) is convenient for adding the carbamate; whilst it would also be suitable for the addition of the iodine in the nickel determination, we feel that, if working on a large scale, a pipette should not be used for iodine because the often repeated inhalation of iodine vapour may lead to toxic symptoms with iodine sensitive operators. A burette of similar accuracy, connected by glass to a reservoir, with little opportunity for vapours to escape—e.g. Griffin and Tatlock, Cat. No. B 17–430 seems preferable.

† Users of other instruments (e.g. Pulfrich, Coleman, etc.) should find it easy to adapt these details to their particular requirements.

‡ We also find the 601 Ilford filters (recommended by Phillips and Edwards,[6]) more selective and, therefore, superior to the filters recommended by other authors, ([4, 2, 3]).

° E.g. 40%, as used with advantage for other purposes.

See ** footnote on next page.

‡ This was suggested, for copper, to the author by Mr. J. H. High (Langley Alloys Ltd.) to whom acknowledgement and thanks are due for this very useful suggestion.

the Ilford filters* ; the use of a fresh batch of reagents may, however, shift the graph slightly and checking is, therefore, advisable.

For very small quantities of copper and nickel higher aliquots of the metal solution may seem desirable in order to increase the accuracy ; this may necessitate adjustment of citric acid and ammonia concentrations [2, 6] and also separation from the silicon‡ in alloys rich in this element. For the higher ranges of copper and nickel, on the other hand, some saving in citric acid might be achieved. The simpler scheme as given above seems, however, to be more suitable, and quite sufficient, for most practical purposes.

(*c*) *Interference by other elements.* The non-interference of the usual alloying elements in the combinations most frequently encountered in commercial alloys has been stated recently[6] under conditions very similar to those outlined above. In extension of these observations we found that the extinctions of copper solutions equivalent to 0·5 –2% Cu on 10 mg of alloy were not altered in presence of up to 2% nickel, 10% magnesium, 0·5% bismuth, 0·5% cobalt, 0·2% lead, 5% tin. The percentages of these added elements would be doubled on alloys with between 2 and 4% of copper as these are measured on smaller aliquots—in other words, up to 4% of nickel would be without measurable influence on alloys with say 4% of copper.

Results on alloys with small copper contents, e.g. 0·25%, are slightly more susceptible to nickel influence : there already 1 to 2% of nickel increase the extinction by 0·01, equivalent to about 0·02% Cu. This combination will however, rarely be found in practice ; 0·5% of nickel is without influence also in this copper range.

Addition of still larger quantities of some of these elements increases slightly the extinctions of copper solutions, as demonstrated by Table II.

TABLE II.
INFLUENCE OF LARGE QUANTITIES OF VARIOUS ELEMENTS.

Metal present	γ in 101 ml	Equivalent to %		Resulting increase of	
		on 10 mg of alloy	on 5 mg of alloy	Extinction	% Cu found *
Ni	400	4	8	·015	·03
Bi	200	2	4	·02	·04
Co	200	2	4	·03	·06
Pb	100	1	2	·01	·02
Cd	10	·1	·2	·005—·01	·01—·02
Cd	50	·5	1	·03	·06

* These values refer to copper quantities equivalent to ·5 to 2% an 10 mg of alloy

Such extreme contents of these metals will rarely be encountered in practice. A correction could be introduced. Still higher contents of nickel—e.g. 10% on alloys with 0·5 to 2% Cu, 20% on those with 2 to 4% Cu —and of cadmium—2 and 4% respectively—produce a turbidity which can only be partly prevented by increasing the quantities of ammonia, citrate or gum arabic. In such cases separations would be required, e.g. for nickel with dimethylglyoxime—see[3], page 52. It will, however, be seen from these data, that the much more complicated technique of extracting the copper-carbamate complex with carbon tetrachloride, as again suggested quite recently[17], need not be resorted to in the vast majority of practically important cases.

In the determination of nickel all the elements in the concentrations as mentioned above were found not to interfere measurably, excepted cobalt ; 0·1% cobalt on 10 mg (0·2% on 5 mg) was still without effect. 0·5%, however, increased the extinction by 0·01, equivalent to an error of about 0·005% nickel on 10 mg samples ; 1% cobalt increased by 0·025, causing an error of 0·015% nickel.

B. Manganese

Here the time honoured transformation into the permanganate seems the most recommendable method and one has to choose between the three main oxidants : bismuthate, persulphate and periodate.

The bismuthate has the advantage of developing the colour without heating—a considerable advantage if aliquots of the same metal solution are to be used for determining several elements (see below) ; this is, however, outweighed by the necessity to filter, particularly as paper cannot be used.

Heating can also be avoided with persulphate under certain conditions, as described by Osborn and Stross[9] and this has found successful practical application for copper alloys.[10] With aluminium alloys and an alkaline attack, however, the traces of chloride which commercial caustic soda usually, distilled water sometimes, contains, produce an interfering turbidity with the silver required as catalyst.

Periodate, recommended by the majority of authors, seemed thus the most practical choice for photometric purposes and the following procedure was adopted as the result of experiments :—

(1) Solutions Required :

(*a*) Standard solution : Dissolve 250 mg of purest electrolytic Mn-metal (99·9) in a little nitric acid, boil to expel nitrous fumes and make up to 1000 ml. Alternatively, use solutions prepared by reducing permanganate with sulphuric acid and nitrite or sulphite.[13]

(*b*) 15% caustic soda, as for copper-nickel method.

(*c*) Acid : 150 ml water, 325 ml conc. nitric acid (Sp. Gr. 1·40) and 25 ml phosphoric acid (Sp. Gr. ca. 1·75).

(*d*) Periodate solution : Shake 7·5 g of the potassium salt with 100 ml 25% (v/v) sulphuric acid until dissolved (not more than a few minutes required).

(2) Procedure :

Attack a 250 mg sample in 250 ml conical beakers with 25 ml caustic solution ; cover with watch glass and when reaction slows down, boil gently for not more than 5 minutes, wash down watch glass with not more than 5 ml of water and add, after slight cooling, 25 ml of the acid with vigorous shaking. Boil 3 minutes without watch glass. Add 2–3 ml of the periodate solution. Cover with watch glass again ; boil gently until the colour starts to develop and then approximately a further 3 minutes, keep hot (e.g. on edge of hotplate) for

* Marking of the edges of the filters has been found useful for this purpose. With the filters in our possession it is not sufficient to observe the marking " Left " and " Right " on the filters ; the measurements obtained vary significantly if the position of the filters is altered.

** As this paper was going to press, the author's attention was drawn to a recent paper by Mitchell and Mellon[16] in which it is stated that the colour of the nickel-dimethylglyoxime complex in aqueous medium is not sufficiently stable for photometric purposes and that ethanol addition stabilises it and should, therefore, be used. The degree of stability of our solutions is very similar to that claimed for the ethanol. We have not investigated the stability of the colour in solutions without citrate, and it seems possible that the citrate, in our case, has an action similar to that claimed for the ethanol, unless some other variation in the conditions—e.g. the use of bromine by Mitchell and Mellon, of iodine in our case, or very high temperature of the laboratory (G. V. L. N. Murty and N. B. Sen, Proc. Indian Acad. Sc., Sect.A., Feb. 1945—provides the true explanation. We find that, without ethanol, the solutions are perfectly stable for at least 30, often 45 minutes after developing the colour.

‡ The following technique seems to be suitable : attack 500 mg with 40 ml 20% caustic (see below) ; acidify with 50 ml 60% perchloric acid, add a few ml nitric acid to dissolve copper, boil down to thick white fumes, cover with watchglass and boil gently a further 10 to 15 minutes. Add some hot water, transfer without filtering into a 100 ml measuring flask, cool, make up to mark and shake well. Filter through 541 Whatman filter and use adequate aliquots of this solution. One is thus sure to have brought all the metallic constituents into solution.

about a further 3–5 minutes, add about 25 ml cold water,* cool and make up to 100 ml.

Measure the light absorbtion in 4 cm cells for contents up to about 0·2%, in 1 cm cells for higher contents up to about 1%, using "Calorex" plus Ilford 604 filters and a setting of 1·30.

Establish the calibration graph by treating suitable aliquots of the standard solution exactly in the same way as the samples, adding, however, the acid first, to prevent formation of MnO_2.

Decolourise[4] by nitrite and remeasure, the difference between the two results expressing the manganese concentration.

(3) Remarks

The discoverers of the periodate method[12] strongly recommended a very high acidity and stated that no harm was done even when this was exceeded. Their experiments were, however, confined to relatively large quantities of manganese and, for small quantities, their views have been contradicted,[13] in experiments on biological materials. We can confirm, for our material, that excess acid interferes with the speedy and complete development of colour. In addition, unnecessarily high acid concentration has a further disadvantage: the risk of precipitating silicic acid on alloys rich in silicon, unless very small samples are used (e.g. 100 mg only[2]), which are however unsatisfactory for the usually low manganese content of these alloys). Very low acid concentration,[4] on the other hand—or the use of excess water in washing down—involves the risk of delayed and incomplete oxidation unless unnecessarily large quantities of the comparatively costly periodate are used. The prescriptions as laid down above form a compromise between these various factors and will ensure a smooth and economical operation if strictly followed.

Most authors seem to add the periodate as the solid which may either lead to inaccuracy of the addition, or may become tedious on a large scale if weighed portions are to be used. The use of tablets, e.g. "Analoids"[4], or of little scoops has been recommended. J. H. High[11] uses, for copper alloys, a rather dilute solution for adding the small quantities of periodate he requires. We find, even with the optimum conditions of acidity, the larger quantities mentioned necessary for our material, and recommend the more concentrated periodate solution described, in order to avoid unnecessary dilution. The requirement of periodate seems not to be determined by simple stechiometric relations only, as it is particularly the low ranges of manganese where a larger excess over the minimum theoretical requirements is necessary. The pronounced period of latency, followed, particularly in the higher ranges, by precipitated development of colour, seems to indicate an autocatalytic reaction. For our material it is also not wise to restrict the quantity of periodate to the barest minimum as then the colour, even if fully developed, may fade rapidly on standing or on diluting with water, in sharp contrast to its well-known remarkable stability in presence of excess reagent.

In chromium free alloys the blank, measured after decolourising, will differ very slightly only from that obtained with water if the outlined procedure has been adhered to. It is usually negligible with a 1 cm cell, and very constant (0·01 to 0·02) with a 4 cm cell so that it need not be determined for more than a few samples out of a large series[4], [5].

We find that a permanganate solution, prepared by dissolving "AR" grade crystals in good quality distilled water, gives a calibration graph identical with that obtained by oxidising the bivalent standard manganese solution (see above). If however, acid and caustic are added, with a view of including "reagent blanks," erroneous results are obtained.

C. Combined Method, including Iron-determination

A very comprehensive scheme, necessitating the use of silver beakers, has been suggested by Vaughan[5]. However desirable a composite scheme may appear it must be born in mind that the solution as recommended is not suitable for all purposes unless a secondary dilution thereof is prepared. This is suggested in Vaughan's scheme but does not seem to us to be a desirable feature. In addition, experience on high silicon alloys shows that such highly concentrated solutions as recommended there, rapidly undergo a peculiar deterioration in regard to silicon. The solutions remain perfectly transparent but the silicon becomes less and less reactive so that already after a short time of standing before colouring up, the results become increasingly low.* If, however, the samples are processed exactly according to the suggestions laid down by the author,[8] (observing, in particular, carefully the addition of water, and not using acid of higher concentration than prescribed) the solutions are stable for at least several, and usually for 24 hours.

We find it very desirable to acidify in the same vessel in which the alkaline attack was performed; this is a further argument against the use of the silver beakers, and in favour of the use of stainless steel beakers[8] for the purpose of silicon determination. Considering carefully the advantages and otherwise of Vaughan's scheme we think that it is more convenient to make a separate weighing for silicon, using stainless steel, and another one, in glass, for other ions.

The metal solution as described before for copper and nickel, i.e. with 1 mg of metal per ml, is suitable also for the determination of iron and, in special cases, of titanium. For iron† pipette 20 ml into a suitable 25 ml measuring vessel, make up to mark, add 2·5 ml 25% KCNS solution and proceed as mentioned below. For the determination of titanium a solution representing 1 mg of alloy per ml cannot be conveniently used for most alloys, it is, however, suitable for key alloys (hardeners) with about 2% to 6% titanium. Pipette 10 to 20 ml into a 50 ml flask and proceed otherwise as described below.

If manganese determination is not desired, this procedure, as compared with the following one, has the advantage of considerable economy of reagents and of quite appreciably speedier manipulation; in addition the aliquots to be pipetted (5, 10 or 20 ml) are more suitable for routine purposes than the smaller ones necessitated by the more concentrated solution described below.

The following slight modifications of the procedure outlined above are recommended for a composite scheme, comprising determination of copper, nickel, manganese and iron from one weighing:

* This to prevent salts from crystallising out during cooling which may not easily be brought into solution again.

9 G. R. Osborn and W. Stross, *Light Metals*, August, 1943.

10 J. R. High, *The Analyst*, **70** (1945) 18.

11 J. R. High, ibidem, **68** (1943), 368.

12 H. H. Willard and L. H. Greathouse, *J. Amer. Chem. Soc.* **39** (1917) 2366.

* This refers to the use of the "yellow molybdate complex" [2], [3] which we prefer to the "blue" for greater simplicity and speed,[4] and also because the "blue" colour reaction is inconveniently sensitive for the higher ranges. We did not investigate this particular question for the blue complex.

† It is recommended for iron determination to clean thoroughly with aqua regia all new vessels prior to taking them into use.

(1) SOLUTIONS :

(*a*) 20% caustic soda (20 g plus 100 ml water).

(*b*) 1350 ml conc. nitric acid, made up to 2000 ml with water.

(*c*) For the photometric manganese determination : add to 100 ml of the periodate solution as described in the preceding chapter, 50 ml of phosphoric acid (S.G. ca. 1·75), taking care not to add the phosphoric acid before the salt is dissolved.

(*d*) For the iron determination, a 25% solution (w/v) of potassium thiocyanate.

The other solutions for copper and nickel remain unchanged.

(2) PROCEDURE

Attack 500 mg of alloy in a 250 ml glass beaker with 40 ml of the caustic, cover with watch glass ; when the vigorous reaction is over, boil gently for not more than 5 minutes, wash down watch glass sparingly, cool for a short while and acidify with 50 ml of the nitric acid, with vigorous swirling. Boil approximately 3 minutes without watch glass, cool, transfer, without filtering, into a 100 ml widenecked measuring flask, mix thoroughly and make up to mark. The liquid evaporated during boiling ensures sufficient space for washing. It may often be more advantageous to double all these quantities. Use for copper and nickel 1 to 2 ml-aliquots, according to content, following otherwise the procedure laid down above for these two elements.

For manganese, pipette a 50 ml aliquot into a 250 ml conical beaker or flask, bring to the boil, take off the hotplate, add 3 to 4 ml of the periodate solution containing phosphoric acid, cover with watch glass and proceed as described.

For iron, pipette a 15 ml aliquot into a wide necked[8] measuring flask with marks at 100 and 110 ml, make up to 100, add, immediately before measuring, 10 ml of the thiocyanate solution, mix and measure without delay the extinction in a 1 cm cell with " Calorex " and Ilford 604 filters, setting at 1·30. Use standard alloys for the purpose of calibration. This covers the range up to about 1·35% Fe.

It may still be pointed out that it is possibly even more economical in time to give the manganese determination a volumetric, instead of a photometric, finish, e.g. by oxidising 50 ml of the above solution with 1 to 2·5 g of ammonium persulphate and 30 to 20 mg of silver nitrate, added as suitable solutions. No further dilution, nor addition of other acids is required. The conditions of heating and subsequent cooling as outlined previously elsewhere[9] should be observed. Addition of some sodium chloride (about 16 mg) before titrating facilitates the recognition of the endpoint with very low manganese concentrations.[15] This procedure saves the weighing and dissolving of a separate sample for the volumetric determination.

The photometric determination of titanium on a further aliquot of this metal solution is also quite feasible (e.g. by pipetting 40 ml of the metal solution, adding of 5 ml 50% (v/v) sulphuric acid, and 2 ml 20 Vol hydrogen peroxide ; then make up to 50 ml, use Ilford 601 filters and a 4 cm cell). As a concentration of 800–1000 mg of alloy in 100 ml final solution is, however, preferable for most of the commercial alloys, if the range of the " Spekker " is to be fully utilised, we cannot generally recommend this procedure.

These investigations were made in the laboratories of Messrs. International Alloys, Ltd., and the author wishes to thank the directors of this company for permission to publish.

13 M. B. Richards, *The Analyst* **55** (1930) 554.
14 Analytical Applications for Periodic Acid and Iodic Acid and their Salts. The G. Frederick Smith Chemical Company, Columbus, Ohio.
15 Chemical Analysis of Aluminium, page 39. Aluminum Company of America. 1941.
16 A. M. Mitchell with M. G. Mellon, *Ind. and Eng. Chem.*, Anal. Ed., **17** (1945) 380.
17 R. F. Partridge, *Ind. and Eng. Chem.*, Anal. Ed., **17** (1945) 422.

Introduction of Simplified Control Procedure for Light Metals, Aluminium, Magnesium and Silicon

A SIMPLIFIED procedure for the control of both raw and fabricated light metals has been introduced.

The general intention of this step is to permit a return to free competition and normal commercial relationship between consumer and producer, except where it may be necessary, for special reasons, to determine otherwise.

Aluminium

The Control of Aluminium (Nos. 5–6) Orders 1940–45, and the Light Metals and Alloys Fabrication (No. 1) Order, remains in force. Statutory obligations concerning licences will therefore remain unaffected but, under the new procedure, running licences will be granted so that users of raw material will be free to purchase and use in any desired amounts, for any purpose, and from any domestic supplier (except for virgin aluminium, where M.A.P. will continue to be the sole trader). New users will need to apply to the Light Metals Control, Banbury, for licences.

Exporters of unwrought aluminium and aluminium alloys will still need to apply for individual licences authorising them to dispose of material to persons outside the United Kingdom.

Users of sheet, extrusions, castings, forgings, or other forms of fabricated aluminium will be free to place orders direct with fabricators. Fabricators will be free to accept Service, Civil, and Export, orders without prior reference to the Control for approval of use or authorisation of fabrication and delivery.

Magnesium

The control of Magnesium (No. 4) Order, 1942, remains in force. No change is contemplated in the present procedure covering monthly licences for acquisition and use of raw material. Users and producers of fabricated magnesium will have the same freedom of action as for fabricated aluminium.

Silicon

The Control of Silicon (No. 1) Order, 1940, has been revoked, whereupon it will cease to be necessary to apply for licences to acquire and use metallic silicon. The Ministry of Aircraft Production will continue to trade as at present, and any person wishing to acquire silicon will simply send his order to the Light Metals Control.

Control Procedure

The Headquarters of the Light Metals Control continues to be at Banbury. The four Fabrication Controls (Sheet and Strip, Extrusions, Castings, and Forgings and Stampings) from September 1st have been amalgamated into one section, operating from the following address : Ministry of Aircraft Production, Light Metals Control, Section LM2, The Vale, Edgbaston Park Road, Birmingham, 15.

Some Recent Appointments

THE appointment of four senior officials to be Special Directors is announced by Dorman Long and Co., Ltd. They are Mr. G. E. Chicken (Commercial Manager), Mr. J. F. Pain, B.Sc., A.M.I.C.E. (Manager, Bridge Dept.), Mr. F. L. Shepherd (Operations Superintendent, Iron and Steel works), and Mr. L. Shuttleworth, M.I.Chem.E. (Manager, Distillation and By-Products Department). These appointments represent a further development of the Company's policy of drawing senior officials into close association with the Board in the direction of the varied activities of Dorman Long.

Mr. G. E. Chicken, who has recently succeeded Mr. A. MacLeod as Commercial Manager, is well known in the iron and steel industry, having been for some years a director and commercial manager of the Appleby-Frodingham Steel Co., Ltd., Scunthorpe.

Major-General READMAN has been appointed a Special Director of English Steel Corporation Limited to assist the Managing Director in the administration of the Works at Openshaw, Dinting Vale and Holme Lane, and also will be in charge of the sales organisation covering the Corporation's small tool and tool steel business and forgings and castings produced at Openshaw.

General Readman's association with the steel industry commenced in 1910 with Vickers Limited, Sheffield, where after gaining considerable experience in various departments and following the formation of English Steel Corporation Limited in 1929, he was appointed Assistant Sales Manager then Sales Manager, later becoming the firms representative in Birmingham.

Mr. H. L. WYNEKEN, A.S.A.A., A.C.W.A., has been appointed secretary and chief accountant to Edgar Allen and Co., Ltd. in succession to Mr. W. H. Higginbotham, who is now Chairman of the Company.

Mr. Wyneken joined the staff of Messrs. Jones, Crewdson and Youatt, Chartered Accountants, of Manchester, in 1924, and remained for a period of 10 years. He then joined Messrs. Frederick Smith & Co., Salford, incorporated with Messrs. London Electric Wire Co. and Smith's Ltd., where he acted as assistant accountant in charge of costs. After three years he accepted an appointment as accountant with Messrs. Beatson Clark Co., Ltd., of Rotherham, glass bottle manufacturers. He was later promoted to the joint position of secretary and accountant and it was from this firm, after a period of service of 7½ years, that he joined Edgar Allen and Co., Ltd.

Mr. F. JACKSON has been appointed by The Carborundum Company Ltd. as their refractory and crucible sales representative for Lancashire, Yorkshire and Cheshire. Mr. Jackson is a past President of the Bristol and West of England Branch of the Institute of British Foundrymen and, in addition to the accumulation of 30 years' foundry experience, he has been active in the teaching of elementary metallurgy and foundry practice.

THE British Iron and Steel Federation announce that the Right Honourable Sir Andrew Rae Duncan, G.B.E., M.P., has accepted an invitation to become Independent Chairman of the Executive Committee of the Federation under the terms of their new Constitution.

MR. A. R. PAGE has resigned his position as Metallurgist to Stewart and Gray Ltd., London, to take up an appointment on the Technical Sales Staff of the Electric Resistance Furnace Co., Ltd., Weybridge. Mr. Page will be responsible for technical sales of heat-treatment salts, stopping-off compounds, heat-treatment furnaces and accessories in the South of England.

THE Government have appointed Lt. General Sir W. G. Lindsell to secure the orderly release of factory space requisitioned for war purposes. This factory space is now urgently required for the expansion of home and export trade, and for implementing the Government's full employment policy.

Information about the de-requisitioning of storage space should still be obtained from the Control of Storage Premises, Board of Trade, Millbank, or from the Board's regional controllers.

Mr. F. E. SMITH and Mr. J. L. S. STEEL have been appointed by the Board of I.C.I. to be additional directors. Mr. F. E. Smith was Chief Engineer and a member of the Board of the Billingham Division of I.C.I., and for a large part of the war has been acting as Chief Engineer and Superintendent, Armaments Design at the Ministry of Supply. Mr. J. L. S. Steel has since 1943 been Chairman of the Alkali Division of I.C.I.

Other appointments announced are that Mr. W. M. Inman, formerly Sales Controller of I.C.I. has been appointed Chairman of the Alkali Division in place of Mr. J. L. S. Steel. Mr. E. M. Fraser, lately Director General of Aircraft Production, has returned to I.C.I. as Sales Controller in place of Mr. W. M. Inman. Mr. A. T. S. Zealley has been appointed Chairman of the Billingham Division and Mr. V. St. J. Killery from Billingham to be Chairman of the General Chemicals Division. Mr. S. A. H. Whetmore has been appointed Managing Director to the Billingham Division jointly with Mr. K. Gordon.

THE Directors of Vickers-Armstrongs Limited announce the following changes in their organisation :—

Commander E. R. Micklem, C.B.E., has relinquished the post of General Manager of the Elswick, Scotswood and Chertsey Works, owing to increasing responsibilities as Deputy Chairman and Managing Director (Engineering Works and Shipyards) of Vickers-Armstrongs Limited.

Mr B. W. A. Dickson has been appointed a Director of Vickers-Armstrongs Limited and General Manager of the Aircraft Section.

Mr. P. H. Muirhead has been appointed a Director of Vickers-Armstrongs Limited and General Manager of the Elswick, Scotswood and Chertsey Works.

Sqd.-Comdr. Sir James Bird, O.B.E., R.N., has relinquished the post of General Manager of the Company's Supermarine Works, and has been appointed Adviser to the Managing Director (Aircraft) of the Company.

Mr. R. K. Pierson, C.B.E., B.Sc., A.M.I.C.E., F.R.Ae.S., has been appointed Chief Engineer of the Aircraft Section of Vickers-Armstrongs Limited.

Mr. G. R. Edwards, B.Sc., A.F.R.Ae.S., A.M.I.Struct. E., is appointed Chief Designer at the Weybridge Works of the Company.

Dr. J. E. HURST has been appointed Sheriff for the City and County of Lichfield, an office which has been in existence for many centuries. We join his numerous friends in congratulating him on this further honour.

A Metallurgical Study of German Aircraft Engine and Airframe Parts

This report constitutes a summary of further data, resulting from the metallurgical examination of German aircraft engine and airframe parts by the Aero-Components Sub-Committee of the Technical Advisory Committee of the Special Alloy Steel Committee formed for that purpose.

The types examined represent a comprehensive range of various types of German aircraft which have fallen into the hands of the R.A.F. from 1942 onwards.

The principal object of these investigations was to obtain data on the types and quality of materials used, methods of manufacture, efficiency of the heat-treatment to which the parts have been submitted, together with any other information which might prove of value, as, for example, details of the finish. Further, the influence of restrictions, due to our blockade, on German procedure and selection of materials was kept in mind. Attention was given chiefly to engine parts but a number of airframe and miscellaneous components were included. Special features concerning design had been noted in certain instances, but these were not the primary object of the investigations. The Sub-Committee responsible for these investigations and for this report comprise; Mr. S. Barraclough, United Steel Companies, Ltd.; Mr. H. Bull, Messrs. Brown-Bayley's Steelworks, Ltd.; Mr. H. H. Burton, the English Steel Corporation, Ltd.; Mr. W. J. Dawson, Chairman, Hadfields, Ltd.; Dr. R. Genders, M.B.E., S.T.A.M., Ministry of Supply; Mr. H. J. Hipkins, Royal Aircraft Establishment: Mr. N. H. Mason, R.A.E., Farnborough; Mr. D. A. Oliver, Messrs. Wm. Jessop and Sons, Ltd.; Mr. L. Rotherham, Thos. Firth and John Brown, Ltd.; Dr. H. Sutton, Ministry of Aircraft Production; Miss M. K. Walshaw, Secretary, Brown-Firth Research Laboratories.

The work included in this report embraces the results of investigations carried out as a continuation of the data already published. It has been carried out meticulously. Naturally in this Report no comparisons are made with corresponding parts in British and American Aircraft, neither are certain aspects which our investigations have shown to be open to criticism emphasised.*

Section III.—Connecting Rods

SINCE the publication of the report summarising the results of examinations approximately up to the beginning of 1943, connecting rods from a further 17 engines have been examined. Many of these represent components from later models of the same types of engines as reported previously.*

Types of Rod

Only one make of air-cooled engine is represented in the present list, the B.M.W. 801 and rods from engines designated B.M.W. 801A/1, B.M.W. 801A/2, B.M.W. 801C/2, B.M.W. 801G and B.M.W. 801G2. These have been received from aircraft as varied as the F.W. 190, Ju. 88 and 188 and Do. 217. The general features of the design of the rods has been maintained throughout these engines, and examination has usually been made on both the main and auxiliary rods.

In the case of the remaining components four were from Mercedes Benz and six from Jumo engines, but in each case the rods were similar to those reported earlier with one "double end" rod and one "single end" rod working together on the same crank pin. The four Mercedes Benz engines comprised examples of the D.B. 605 (and 605 A1), D.B. 603 and D.B. 601N and the Jumo engines while mainly Jumo 211F and Jumo 211J include a Jumo 213A1. Differences in design between the D.B. types were slight but the Jumo 213A1 rod was of a shorter length than examples of the Jumo 211. Generally differences of detail were apparent in a number of the rods.

Analyses

In the B.M.W. 801 types two composition variants are to be noted; a 2½ per cent. chromium-molybdenum-vanadium type for the main rods and a 1 per cent. chromium-molybdenum-vanadium for the auxiliary rods. Molybdenum was present in all the main rods and vanadium in all but one and in this particular case, the absence of vanadium occurred with the highest molybdenum content (0·36%) recorded. The last sample examined (item No. 267) showed the lowest molybdenum content (0·10%). In the case of the auxiliary rods, the four examples from B.M.W. 801A engines all but one (item No. 214) contain molybdenum between 0·16 and 0·23% while the rod from a B.M.W. 801C (item No. 166) contained 0·11%; the rod from a B.M.W. 801G (item No. 255) contained 0·07% while the rod from a B.M.W. 801G2 contained only a trace. There is therefore some evidence of conservation of molybdenum in the later types and this is offset by a tendency for the use of vanadium instead. No extensive examination of auxiliary parts has been made on these rods but in the case of item No. 207 it is noted that the material of a bolt is of the same analysis type as the auxiliary rod.

Examination of a double big end rod (item No. 154) confirms the use of 1% Cr Mo steel in the D.B. 601 engine but this is replaced by 2½% Cr V in the one example of the D.B. 603 (item No. 261) and in the latest case of the D.B. 605 (item No. 291) but in the earlier example of the D.B. 605 (item No. 234) a 2½% Cr Mo V steel was used.

The earlier examples of the Jumo 211 were found to be of a 2% nickel, 2½% chromium-molybdenum steel but in the later examples (items Nos. 227 and 247) the introduction of vanadium was noted and in the latest type, the Jumo 213 (item No. 302) the steel used was 2½% chromium-vanadium with the absence of molybdenum. This evidence tends to confirm the impression of the B.M.W. engines that some conservation of molybdenum was being attempted over a long period.

* "A Metallurgical Study of German and Italian Aircraft Engine and Airframe Parts," 1943, The Kennedy Press, Limited.

Mechanical Tests

A definite difference in maximum strength between the main and auxiliary rods was apparent in the case of the B.M.W. engines. Taken as a whole the main rods ranged between 62·3 and 71·2 tons/sq. inch maximum stress while the auxiliary rods were from 66·8 to 80·5 tons/sq. inch maximum stress. In general the latter rods were 6 to 12 tons/sq. inch higher in maximum stress than the main rod in the same engine, and only in one case (item No. 166) was a higher value noted in the main rod than in the auxiliary rod.

In the D.B. engines no such comparison can be made between the double and single end rods. In the two cases where both rods from the same engine have been examined, the double end rod was slightly higher in maximum stress. The overall range of values was from 72·5 to 61·4 tons/sq. inch with a tendency for the later engines to show the lower values. In view of the small number of examples however too much attention should not be paid to this observation.

The maximum stress values recorded on the Jumo 211 engines range from 68·7 tons/sq. inch to 74·1 tons/sq. inch, which may be regarded as a relatively narrow range and there does not appear to be any tendency for the double end rod to be higher in strength than the single end rod. On the one Jumo 213 engine, the double end rod gave a maximum stress value of 61·5 tons/sq. inch and the single end rod 58·0 tons/sq. inch. This rod was of course from the Cr V steel whereas all the others contained an appreciable quantity of nickel.

Izod values are not recorded since in general there was insufficient material for a standard test-piece. Where values were recorded on test-

CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES OF RODS AND AUXILIARY PARTS (STEEL) FROM B.M.W ENGINES.

Item No.	Type	C	Si	Mn	S	P	Ni	Cr	Mo	V	Cu	Inherent Grain Size	Y.P. or ·5% P.S.	Max. Stress	Elong. %	Hardness Case (Diam Nos.)	Hardness Core (Brinell)
146	B.M.W. 801A/1 (Do. 217E/1)																
	Main Rod	0·29	0·24	0·61	0·009	0·010	0·21	2·61	0·14	0·15	0·05	6 to 7	—	71·2	22	861	340
	Auxiliary Rod	0·42	0·39	0·56	0·007	0·010	0·31	1·04	0·19	nil	0·11	6 to 7	74·8	80·5	18½	—	364–381
166	B.M.W. 801C/2 (F.W.190A/2)																
	Main Rod	0·32	0·20	0·57	0·012	0·021	0·15	2·56	0·28	0·22	0·11	8	63·0	68·5	15½	853	328–357
	Auxiliary Rod	0·36	0·24	0·74	0·008	0·016	0·14	1·02	0·11	nil	0·09	6	61·4	66·8	18	—	332
207	B.M.W. 801A/2 (Do. 217E/4)																
	Main Rod	0·33	0·30	0·77	0·011	0·012	0·21	2·39	0·24	0·20	0·05	7	—	63·0	18½	824	302
	Auxiliary Rod	0·43	0·19	0·48	0·010	0·014	0·32	1·03	0·16	nil	0·09	6	59·6	70·5	16½	—	351–375
	Bolt	0·38	0·3	0·65	—	—	low	1·2	0·2	—	—	—	—	—	—	—	262–269
214	B.M.W. 801A/2 (Do. 217E/2)																
	Main Rod	0·28	0·36	0·67	0·005	0·007	0·08	2·50	0·22	0·19	0·14	7	—	—	—	836	282–285
	Auxiliary Rod	0·51	0·27	0·63	0·013	0·006	0·36	1·11	trace	0·15	0·21	5 to 6	—	—	—	—	375–396
241	B.M.W. 801A (Do. 217E/4)																
	Main Rod	0·33	0·24	0·68	0/006	0·009	0·43	2·46	0·31	0·16	0·07	6 to 7	—	—	—	836	282–291
	Auxiliary Rod	0·38	0·29	0·62	0·015	0·012	0·08	1·09	0·23	trace	0·14	6 to 7	—	—	—	—	374–386
255	B.M.W. 801G (Ju 88-81)																
	Main Rod	0·26	0·29	0·55	0·005	0·015	0·10	3·14	0·36	nil	0·04	4 to 6	53·6	62·3	17½	804	293–299
	Auxiliary Rod	0·50	0·23	0·77	0·008	0·017	0·18	1·21	0·07	0·18	0·10	Mixed 2, 4 & 6	70·6	74·0	16	—	373–379
267	B.M.W. 801G2 (Ju 188E/1)																
	Main Rod	0·27	0·26	0·49	0·013	0·016	0·28	2·13	0·10	0·20	0·10	7 to 8	60·4	64·0	18	792	293–302
	Auxiliary Rod	0·49	0·17	0·66	0·028	0·016	trace	1·01	trace	0·10	0·06	Mixed 4 to 7	67·0	70·5	15	—	311

CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES OF RODS AND AUXILIARY PARTS (STEEL) FROM D.B. ENGINES.

Item	Type	C	Si	Mn	S	P	Ni	Cr	Mo	V	Cu	Inherent Grain Size	Y.P. or ·5%P.S.	Max. Stress	Elong. %	Red. of Area %	Brinell Hardness
154	D.B.601N (Me 109E)																
	Double big end rod	0·37	0·30	0·75	0·026	0·018	0·01	1·20	0·23	nil	0·15	—	—	—	—	—	311–332
	Bolt	0·36	0·33	0·60	0·023	0·016	4·55	1·41	trace	nil	0·26	—	68·4	72·5	18½	54½	321–343
	Nut	0·39	0·34	0·63	—	—	0·23	1·25	0·12	nil	By spectro except C.	—	—	—	—	—	263–310
	Roller Race	1·05	0·27	0·30	0·021	0·024	trace	1·44	nil	nil	0·15	—	—	—	—	—	760–777 (Diamond)
234	D.B.605A/1 (Me 109G)																
	Single big end rod	0·36	0·35	0·57	0·008	0·011	0·13	2·54	0·30	0·24	0·23	7	60·5	66·6	19	—	321–340
	Double „ „ „	0·34	0·34	0·59	0·008	0·014	0·18	2·63	0·25	0·25	0·19	7	62·7	67·9	19	—	332–340
	Single end rod Bolt	—	0·24	0·57	—	—	nil	2·19	nil	0·20	— (by spectro graph.)	—	—	—	—	—	293
	„ „ „ Nut	—	0·27	0·57	—	—	nil	0·83	0·14	nil	—	—	—	—	—	—	298
	Double end rod Bolt No. 1	—	0·23	0·60	—	—	nil	2·49	0·17	0·19	—	—	—	—	—	—	274
	„ „ „ „ „ 2	—	0·28	0·63	—	—	nil	1·84	0·37	0·20	—	—	—	—	—	—	306
	„ „ „ Nut	—	0·45	0·50	—	—	nil	1·17	0·18	nil	—	—	—	—	—	—	277
261	D.B.603 (Do. 217-M1)																
	Single big end rod	0·33	0·29	0·57	0·008	0·014	0·28	2·46	0·04	0·16	0·09	Mixed 1 & 5	56·3	61·4	17	—	321–338 (surf.) 285 below surf.
	Double big end rod	0·33	0·28	0·50	0·007	0·017	0·19	2·42	0·03	0·19	0·13	4 to 6	61·1	64·2	15½	—	293–344
	Single end rod—Bolt	0·27	—	0·63	—	—	low	2·52	nil	0·27	—	—	—	—	—	—	317–341
	„ „ „ Nut	0·59	—	0·62	—	—	low	1·01	nil	0·18	—	—	—	—	—	—	298–307
	Double end rod—Bolt 1	0·27	—	0·63	—	—	low	2·52	nil	0·27	—	—	69·5	74·0	21½	64½	298–325
	„ „ „ Bolt 2	—	—	0·79	—	—	low	1·30	nil	0·18	— (by spectro graph.)	—	—	—	—	—	—
	„ „ „ Nut	—	—	0·77	—	—	low	0·95	nil	0·17	—	—	—	—	—	—	280–326
291	D.B.605 (He 177)																
	Double big end rod	0·34	0·32	0·47	0·019	0·015	0·14	2·41	trace	0·29	—	—	—	—	—	—	293–324 (30 Kg Diam.)

CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES OF RODS AND AUXILIARY PARTS (STEEL) FROM JUMO ENGINES.

Item No.	Type	C	Si	Mn	S	P	Ni	Cr	Mo	V	Cu	Inherent Grain Size	Y.P. or ·5% P.S.	Max. Stress	Elong. %	Red. of Area %	Brinell Hardness
160	Jumo 211J (Ju. 88D1)																
	Double big end rod	0·29	0·24	0·46	0·013	0·010	1·87	2·53	0·20	nil	0·14	5 to 6	65·5	71·9	19	—	332–351
	" " " " Bolt ..	0·36	0·45	0·67	0·010	0·007	0·24	2·51	0·27	0·14	0·12	—	64·8	71·9	20	65	—
	" " " " Nut ..	0·39	0·29	1·42	—	—	0·18	0·30	—	—	—	—	—	—	—	—	309–333
182	Jumo 211J1 (Ju 88D-1)																
	Double big end rod	0·33	0·31	0·62	0·006	0·015	1·81	2·18	0·23	nil	0·12	6 to 7	69·6	74·0	16½	—	343–364
	" " " " Bolt ..	0·28	0·31	0·52	—	0·013	0·2	2·7	0·15	0·21	—	—	62·9	68·4	22	67½	317
	" " " " Nut ..	0·43	0·30	0·49	—	—	0·33	1·2	0·13	—	—	—	—	—	—	—	326–331
209	Jumo 211F1																
	Double big end rod	0·34	0·23	0·37	0·006	0·017	1·53	2·42	0·27	trace	0·10	6 to 7	—	73·5	13	—	346–395
	" " " " Bolt ..	0·33	0·33	0·67	—	—	low	2·45	0·15	·1/·2	—	—	75·5	79·6	18½	57½	351–395
	" " " " Nut ..	—	·2/·35	1·3/1·6	—	—	low	low	less than 0·1	nil	—	—	—	—	—	—	295–340
	Single big end rod	0·26	0·27	0·49	0·010	0·010	2·62	2·40	0·21	trace	0·19	6	67·1	74·1	20	—	364–373
	" " " " Bolt ..	0·49	0·27	0·86	—	—	low	1·1	less than 0·1	·1/·2	—	—	68·2	71·4	18½	57½	332
	" " " " Nut ..	0·40	0·30	1·45	—	—	0·4	0·4	less than 0·1	nil	—	—	—	—	—	—	293–340
227	Jumo 211F1 (Ju 88)																
	Double big end rod	0·32	0·26	0·44	0·009	0·011	1·69	2·70	0·14	0·23	0·12	6 to 7	67·1	70·6	20	—	342–350
	" " " " Bolts	—	0·28	0·64	—	—	nil	0·90	nil	0·15	—	—	—	—	—	—	302–329
	" " " " Nuts ..	—	0·25	0·58	—	—	0·15	1·21	0·20	nil	—	—	—	—	—	—	313–335
	Single big end rod	0·33	0·30	0·40	0·009	0·009	1·65	2·55	0·11	0·26	0·16	6 to 7	69·1	71·9	16	—	350–364
247	Jumo 211 (Ju 88A-14)																
	Double big end rod	0·34	0·30	0·60	0·015	0·020	1·69	1·85	0·22	0·15	0·15	7 to 8	63·8	73·5	13½	—	364–379
	" " " " Bolt ..	—	0·28	0·64	—	—	0·17	0·92	nil	0·11	—	—	—	—	—	—	280–285
	" " " " Nuts ..	—	0·30	1·30	—	—	0·10	0·14	nil	nil	—	—	—	—	—	—	282–288
	Single big end rod	0·32	0·33	0·54	0·031	0·027	1·96	1·86	0·23	0·15	0·14	4 to 5	64·8	68·7	14½	—	249–252
302	Jumo 213A1 (Ju 188)																
	Double big end rod	0·31	0·29	0·72	0·007	0·026	0·30	2·37	nil	0·19	0·15	—	56·0	61·5	21	—	292–317
	" " " " Bolt ..	0·46	0·26	1·3	0·037	0·014	0·50	0·22	nil	0·08	—	—	63·8	69·0	20	55	333
	" " " " Nuts ..	0·35	0·21	1·4	0·007	0·034	0·10	0·28	nil	nil	—	—	—	—	—	—	327
	Single big end rod	0·36	0·40	0·63	0·009	0·007	0·20	2·44	nil	0·29	0·08	—	50·8	58·0	22½	—	246–317

pieces of non-standard size they indicated an adequate level of values.

Manufacture of Steel

With two exceptions on D.B. engines (items No. 154 and 291), one on the auxiliary rod of a B.M.W. engine (item No. 267), and one on the single end rod on a Jumo engine (item No.247) all the values of sulphur content were below 0·015 and many were below 0·010. In the case of these four items the standard of cleanliness was lower than in the remainder and it was concluded that these four materials were probably of acid open hearth manufacture with the remainder made in the electric furnace. These remarks apply essentially to the rods but are probably applicable to the nuts and bolts examined although in this case the examination was less detailed and no deduction drawn.

Manufacture and Heat-treatment of Rods

The examination made of rods of different types gave no indication that any had been made other than as forgings or drop forgings. Where macro structures were examined they indicated a satisfactory flow structure.

In the majority of cases, heat-treatment had resulted in a very satisfactory structure consisting of fine sorbite. In a few cases however on the single ended rods or on the auxiliary rods of the B.M.W. engines, the heat-treatment had been less satisfactory. For instance on the single and double ended rods from a D.B. 605A/1 reported under item No. 234, the double end rod was quite satisfactory but on the single end rod, a coarse overheated structure was observed although this was not associated with an abnormally low Izod value.

Under item No. 247 on rods from a Jumo 211, both rods showed a coarse structure but the effect was most marked on the single end rod. The Izod value in this case was rather lower as was also the elongation values.

The main rods in the B.M.W. engines were nitrided with a case hardness of the order of 800 diamond hardness number.

Surface Finish

The surface finish on most of the rods was good. Earlier examples appeared mainly to be smooth lapped except in the case of the B.M.W. engines where a shot blast finish appeared to be more common. In item No. 241 however a pair of B.M.W. rods was dealt with in which a smooth lapped finish was observed while in item No. 247 it was noted that shot blasting had been resorted to on components from a Jumo 211 engine. In this latter case moreover, the heads of the bolts had not been polished after heat-treatment. There appeared to be some general reduction in the quality of finish in the later components.

General Remarks

The notable features brought out by this series of investigations may be summarised as follows :—

(1) The use of nickel-chromium-molybdenum steels had gradually been replaced by the use of chromium-molybdenum types.

(2) There was a gradual trend towards the replacement of the molybdenum in these latter steels by vanadium.

(3) With the chromium-vanadium types there appeared to be a tendency to work at a lower level of maximum stress.

(4) Heat-treatment was not consistently satisfactory there being a number of examples of coarsening of the structures.

(5) Surface finish variations were towards a less highly finished product.

All these conclusions would appear to be consistent with a steadily worsening alloy supply position or with a desire to economise in time spent in fabrication. The due weight to be attached to this conclusion is uncertain since the number of components examined is still relatively small and there is no evidence whatever that the parts would not give a satisfactory service life.

Section IV.—Gudgeon Pins and Wrist Pins

A. GUDGEON PINS

Seventeen gudgeon pins have been examined, and of these, five were from the Jumo 211 type of engine, one from the Jumo 213, seven from the B.M.W. 801, one each from the D.B. 601 and D.B. 603 types, and two from the D.B. 605 type. Details of these pins are given in Table I.

Visual Examination

Most of the pins showed two or three distinct, as well as less marked rings of a brown deposit similar to those noted on pins examined previously. In general the outer surfaces of the German pins showed a well lapped finish, which had become scratched in service, indicating a normally maintained standard of workmanship, though in the case of the B.M.W. 801 pin (item No. 134) the surface was not of the usual standard, showing only a rough emery finish. In some pins both the ends and the bore were fine ground, while in others the bore was ground and the ends were fine machined.

Analysis

All the steels were made by the basic electric-arc process.

Of the six Jumo pins, five were made from carburising steels, two of which were of 1½/2% nickel, 2% chromium-molybdenum steel, while the other three were of the 0·20/0·25% carbon, 1/1¼% manganese, 1¼% chromium type. The pins previously examined in item No. 117 were of this last type with a molybdenum content of 0·20%, so that the absence of molybdenum in the present pins suggests an economy measure. The remaining Jumo pin, from a Jumo 213 engine, was of the 2½% chromium-vanadium nitriding type with only a low molybdenum content of 0·08%. All the B.M.W. pins were made from nitriding steel containing approximately 2½% chromium, 0·20% vanadium with a variable molybdenum

TABLE I—GUDGEON PINS.

Item No.	Type of Engine	C	Si	Mn	S	P	Ni	Cr	Mo	V	Cu	Al	W	N	Surface Treatment	Mechanical Properties			Diamond Hardness		Case Depth in.	McQuaid Ehn Grain Size.
																M.S	El%	RA%	Case	Core		
161	Jumo 211 J1 ..	0·16	0·30	0·44	0·006	0·011	1·63	2·15	0·235	Tr.	0·145	0·013	—	0·012	Carb'd.	83·1	23·6	69·7	737–752	367	Outside 0·024 Inside 0·019	5–6
184	Jumo 211 J1 ..	0·13	0·32	0·48	0·010	0·009	1·94	1·92	0·36	Nil	0·11	—	Nil	0·012	Carb'd	83·0	24·7	69·1	732–763	401	Outside 0·038 Inside 0·033	6
250	Jumo 211	0·23	0·28	1·19	0·010	0·014	0·16	1·36	Tr.	Nil	0·08	—	—	0·014	Carb'd.	—	—	—	690–715	—	Outside 0·028 Inside 0·021	—
224	Jumo 211 F1 ..	0·23	0·29	1·24	0·007	0·015	0·12	1·29	Tr.	Tr.	0·10	—	—	0·014	Carb'd.	75·5	24·0	69·0	690–757	349	Outside 0·050 Inside 0·048	3–7 Mainly 5
229	Jumo 211 F1 ..	0·21	0·37	1·19	0·008	0·018	0·12	1·34	Tr.	Nil	0·12	—	—	0·013	Carb'd.	95·5	22·0	64·5	690–715	450	Outside 0·044 Inside 0·044	3–6 Mainly 4–5
303	Jumo 213 A1 ..	0·31	0·345	0·61	0·011	0·013	0·19	2·41	0·08	0·26	0·10	—	—	—	Nitrided	—	—	—	879	343	Outside 0·017 Inside 0·018	Abnormal
134	B.M.W. 801 ..	0·28	0·23	0·86	0·018	0·015	0·35	2·43	0·27	0·17	0·06	0·007	—	0·013	Nitrided	78·0	21·0	50·8	835–855	360	Outside 0·014 Inside 0·014	Abnormal
244	B.M.W. 801 A ..	0·28	0·26	0·80	0·008	0·017	0·36	2·52	0·34	0·19	0·11	—	—	0·012	Nitrided	78·0	24·0	63·0	741–876	374	Outside 0·012 Inside 0·015	5–7 Mainly 6
205	B.M.W. 801 A2	0·31	0·205	0·64	0·011	0·014	Tr.	2·68	0·18	0·21	—	—	—	—	Nitrided	—	—	—	792–828	349	Outside 0·012 Inside 0·015	—
216	B.M.W. 801 A2	0·30	0·245	0·71	0·005	0·015	0·13	2·35	Nil	0·215	0·11	—	—	0·013	Nitrided	67·9	28·0	62·0	652–690	322	Outside 0·014 Inside 0·015	4–5
168	B.M.W. 801 D2	0·31	0·30	0·68	0·006	0·015	0·35	2·41	0·30	0·16	0·105	—	Nil	0·012	Nitrided	78·5	22·6	57·8	786–810	363	Outside 0·016 Inside 0·018	Abnormal
257	B.M.W. 801 G ..	0·23	0·335	0·61	0·008	0·016	0·165	2·55	0·22	0·21	0·11	—	—	0·012	Nitrided	—	—	—	849–890	—	Outside 0·018 Inside 0·019	—
268	B.M.W. 801G2	0·33	0·31	0·71	0·009	0·014	0·11	2·37	Tr.	0·23	—	—	—	—	Nitrided	—	—	—	792–813	—	Outside 0·013 Inside 0·013	—
156	D.B. 601 N ..	0·31	0·33	0·58	0·010	0·006	0·14	2·57	0·15	0·17	0·10	0·005	—	0·006	Nitrided	—	—	—	786–816	—	Outside 0·021 Inside 0·017	Abnormal
263	D.B. 603	0·31	0·29	0·59	0·011	0·015	0·21	2·59	0·18	0·17	0·21	—	—	—	Nitrided	—	—	—	823–876	373	Outside 0·024 Inside 0·013	—
294	D.B. 605	0·32	0·36	0·51	0·008	0·009	0·20	2·58	0·06	0·16	—	—	—	—	Nitrided	—	—	—	724	290	Outside 0·023 Inside 0·021	Abnormal
236	D.B. 605 A1 ..	0·25	0·335	0·52	0·008	0·015	0·20	2·46	0·17	0·195	0·07	—	—	·012	Nitrided	73·5	24·0	63·0	804–843	360	Outside 0·028 Inside 0·020	Abnormal

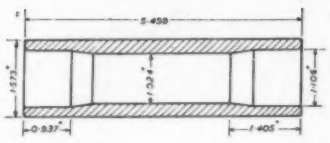


Fig. 1.—Dimensions of Jumo 211–J.1 gudgeon pin.

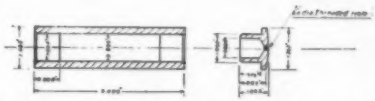


Fig. 2.—Dimensions of Jumo 213–A.1 gudgeon pin.

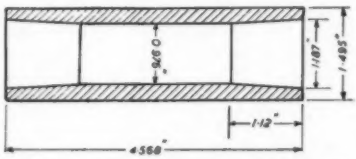


Fig. 3.—Dimensions of B.M.W. 801 gudgeon pin.

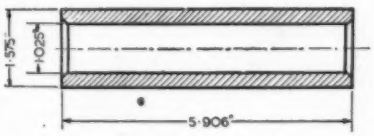


Fig. 4.—Dimensions of D.B. 603 gudgeon pin.

content—two of the pins contained no molybdenum, two approximately 0·20%, and three approximately 0·30% molybdenum. The four pins from the D.B. engines were of the 2½% chromium-vanadium type with low molybdenum contents of 0·06/0·18%.

Grain Size

The grain size of the steels from which the gudgeon pins were produced was variable, and in some cases the steel was abnormal.

Magnetic Etch Tests and Sulphur Prints

No cracks or other defects were revealed in the pins by magnetic etching, and they were shown to be free from segregation by sulphur printing.

Macroscopical Examination

Etched cross sections revealed uniform carburised or nitrided cases on the outer and inner surfaces of the German pins, while etched longitudinal sections showed well defined and uniform flow structures.

Hardness Tests

The hardness of the outer surface of the pins was explored, as well as hardness determinations made on the ends of the pins. The results obtained on the ends of the pins are tabulated as below:—

Hardness values were also determined through the thickness of the cross-section of the German pins, and the results for some of the pins are shown plotted against distance from the outer surface in Figs. 5 to 14. The pins were carburised or nitrided on both the outer surface and the bore, and the hardness gradients from the two surfaces were similar. In most of the pins the actual hardness values of the two surfaces were similar, although in some the hardness of the bore surface was slightly lower than that of the bearing surface.

Microscopical Examination

(*a*) *Cleanness.*—In most of the pins the steel was not equal to the British standard of cleanness in steel for gudgeon pins. The inclusions present consisted mainly of fine elongated sulphides, with small angular oxide particles and occasional small streaks of silicate up to 0·010 in. in length.

(*b*) *Microstructure* — The carburised pins showed in the cases a fine structure with some free carbide, varying from a fine network, extending to a depth of 0·006 in., to small particles of carbide without a network, and in the cores the structure consisted of dense sorbite with a slight martensitic aspect.

The outer cases of the nitrided pins had been ground, but in most of the pins the inner cases were complete showing the γ' constituent to a depth of 0·0005 in. The general structure of the cases was fine with a slight needle-like appearance, while that of the

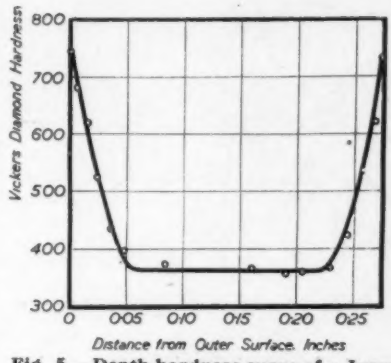


Fig. 5.—Depth hardness curve of a Jumo 211–J.1 gudgeon pin.

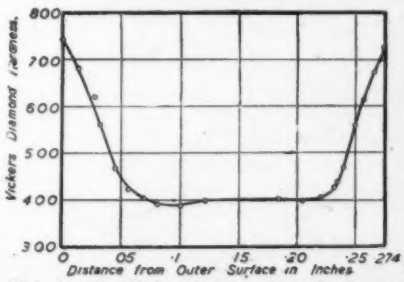


Fig. 6.—Depth hardness curve of a Jumo 211–J.1 gudgeon pin.

Item No.	Type of Engine	Comparison of Ends with Surface	Diamond Hardness of Ends
161 ..	Jumo 211 J1..	Variable and generally lower than surface.	712—763
184 ..	Jumo 211 J1..	Variable and generally lower than surface.	673—762
224 ..	Jumo 211 F1	Variable and generally higher than surface.	710—804
229 ..	Jumo 211 F1	Variable and lower than surface.	640—690
134 ..	B.M.W. 801	Similar to surface.	—
244 ..	B.M.W. 801 A	Variable and generally higher than surface.	769—919
205 ..	B.M.W. 801 A2	Similar to surface.	—
216 ..	B.M.W. 801 A2	Equal to core hardness.	—
168 ..	B.M.W. 801 D2	Variable and generally lower than surface.	743—803
156 ..	D.B. 601 N	Slightly lower than surface.	760
236 ..	D.B. 605 A1	Variable and lower than surface.	725—775

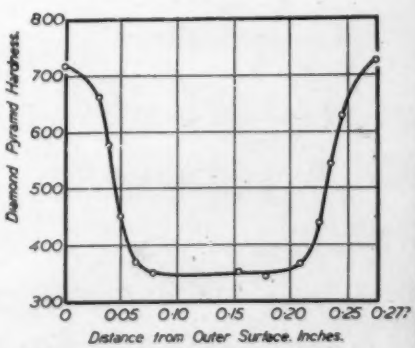


Fig. 7.—Depth hardness curve of a Jumo 211–F.1 gudgeon pin.

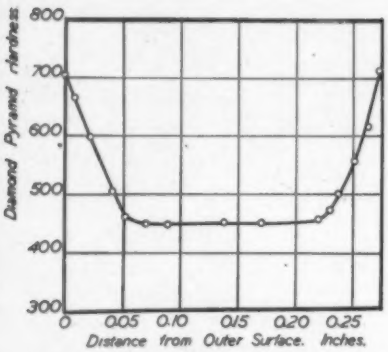


Fig. 8.—Depth hardness curve of a Jumo 211-F.1 gudgeon pin.

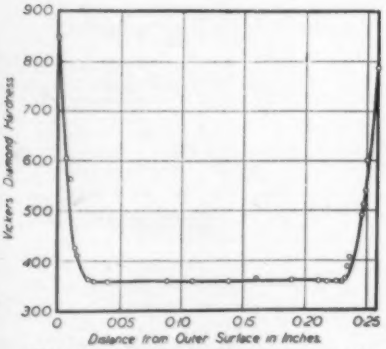


Fig. 9.—Depth hardness curve of a B.M.W. 801 gudgeon pin.

cores showed dense sorbite with fairly marked banding in several pins.

Figs. 15 to 18 illustrate the structures of some of the gudgeon pins examined.

B. WRIST PINS

Only three wrist pins have been examined, all from B.M.W. 801 engines

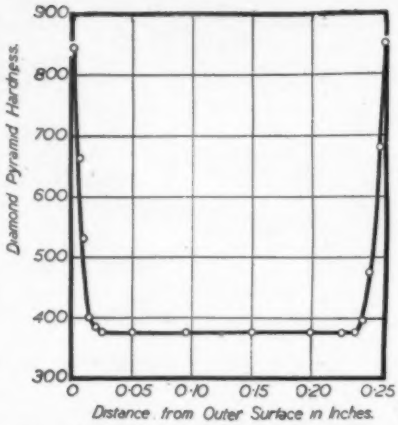


Fig. 10.—Depth hardness curve of a B.M.W. 801–A gudgeon pin.

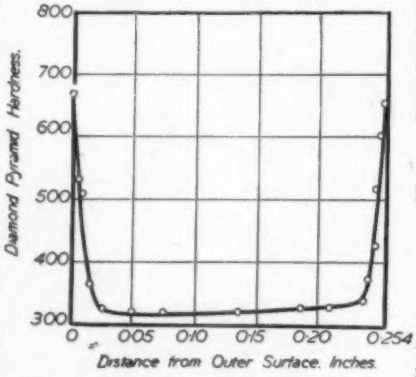


Fig. 11.—Depth hardness curve of a B.M.W. 801–A.2 gudgeon pin.

and the results are summarised in Table II.

Visual Examination

The appearance of the wrist pin from the B.M.W. 801 A1 showed a

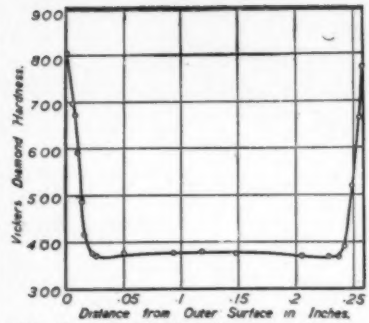


Fig. 12.—Depth hardness curve of a B.M.W. 801–D.2 gudgeon pin.

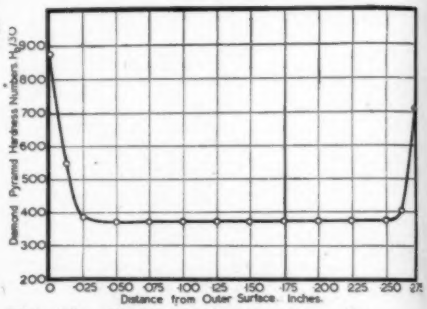


Fig. 13.—Depth hardness curve of a D.B. 603 gudgeon pin.

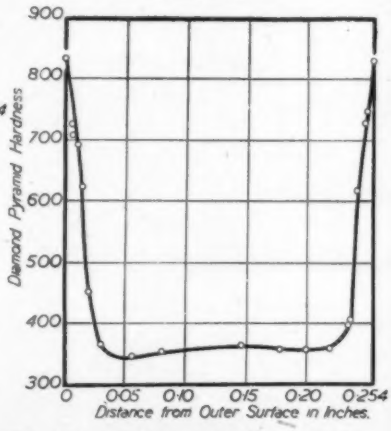


Fig. 14.—Depth hardness curve of a D.B. 605–A.1 gudgeon pin.

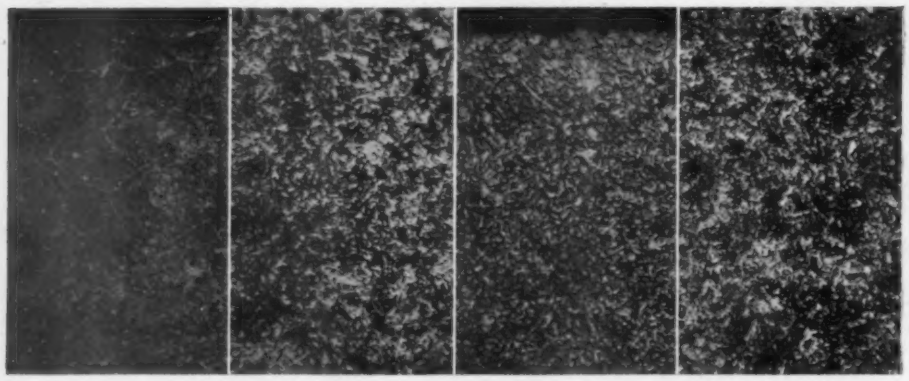
Photomicrographs numbered from left to right.

Fig. 15.—Structure of carburised case of Jumo 211–J.1 gudgeon pin (Engine 1957). ×300.

Fig. 16.—Structure of core of Jumo 211–J.1 gudgeon pin (Engine 1957). ×300.

Fig. 17.—Structure of nitrided case of B.M.W. 801 gudgeon pin (Engine 80015). ×300.

Fig. 18.—Structure of core of B.M.W. 801 gudgeon pin (Engine 80015). ×300.



finely ground finish on both outer and inner surfaces with evidence of weer at the centre of the outer surface. The dimensions of the two pins from the B.M.W. 801G engines were slightly different from those of the B.M.W. 801A engine and the dimensions of both types of pin are illustrated in Figs. 19 and 20.

Analysis

All the pins were nitrided, and the composition

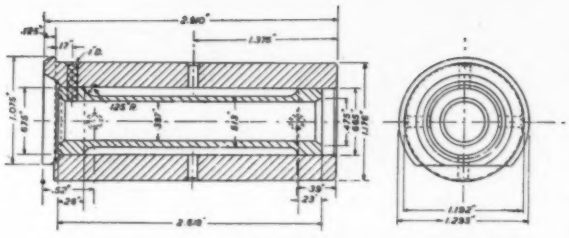


Fig. 19.—Dimensions of B.M.W. 801–A.1 wrist pin.

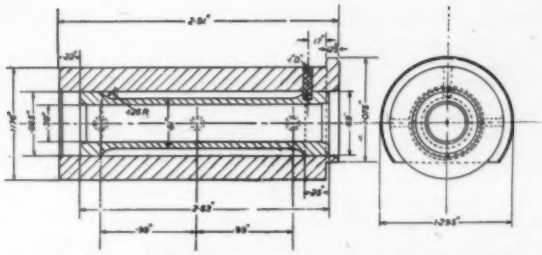


Fig. 20.—Dimensions of B.M.W. 801–G. wrist pin.

of the steel, which was of basic electric-arc manufacture, was of the 2½% chromium, 0·20% vanadium type, with a molybdenum content ranging from a trace to 0·20%.

Macroscopical Examination

Magnetic etching, sulphur printing and etched sections did not reveal cracks or segregation, and there was no evidence of deterioration in the quality of the material.

Hardness Tests

Hardness determinations carried out on the surfaces of the pins indicated a fairly uniform hardness on any particular pin, the hardness of that from the B.M.W. 801A engine being, however, markedly higher than the hardness of the other two pins. The hardness values of the flanged ends were similar to those of the outer surfaces, but the hardness of the other ends was definitely lower, being approximately 650 diamond hardness.

On two of the wrist pins, further hardness tests were carried out on the cross section through the wall of the pin. The pins were nitrided on both the outer surface and the bore, and the hardness gradients and the actual hardness values of the two surfaces were similar. The results are shown in Figs. 21 and 22, plotted against distance from the outer surface.

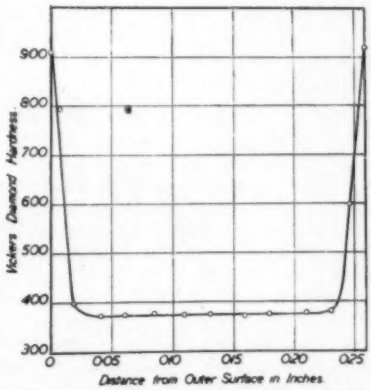


Fig. 21.—Depth hardness curve of B.M.W. 801–A.1 wrist pin.

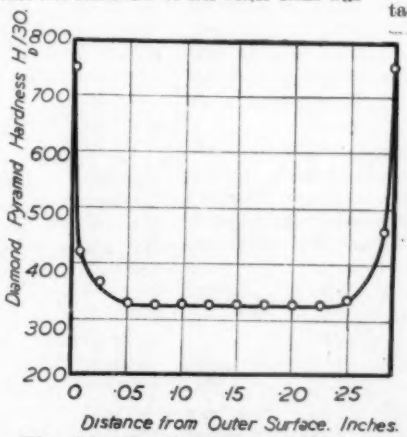


Fig. 22.—Depth hardness curve of B.M.W. 801–G. wrist pin.

Microscopical Examination

(*a*) *Cleanness.*—The steel was fairly clean, but not equal to the standard required for similar British components.

(*b*) *Microstructure.*—The case and core structures of two of the pins are illustrated in Figs. 23 to 26. The outer cases had been ground after nitriding, and the structures showed a dense sorbitic condition with a marked network in the case of the pin from the B.M.W. 801 G engine, while the core structure of this pin was considerably finer than that of the pin from the B.M.W. 801 A1 engine.

Table II overleaf.

To be continued.

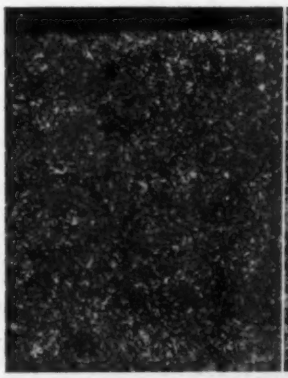


Fig. 23. — Structure of nitrided case of B.M.W. 801–A1 wrist pin. ×300.

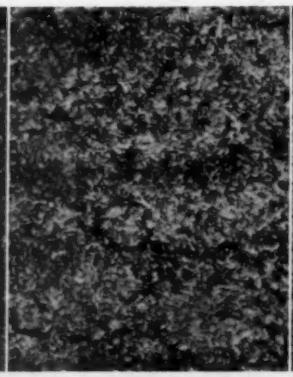


Fig. 24. — Structure of core of B.M.W. 801–A.1 wrist pin. ×300.

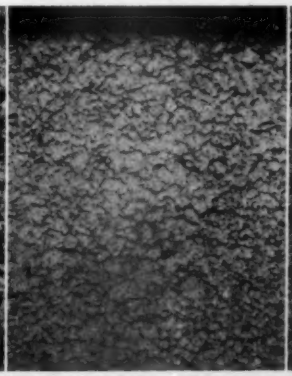


Fig. 25. — Structure of nitrided case of B.M.W. 801—G. wrist pin. ×300.

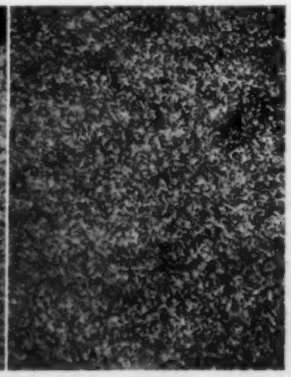


Fig. 26. — Structure of core of B.M.W. 801–G. wrist pin. ×300.

TABLE II—WRIST PINS.

Item No.	Type of Engine	C	Si	Mn	S	P	Ni	Cr	Mo	V	Cu	Al	W	N	Surface Treatment	Mechanical Properties			Diamond Hardness		Case Depth in.	McQuaid Ehn Grain Size
																M.S	El%	RA%	Case	Core		
147	B.M.W. 801 A1	0·27	0·29	0·71	0·008	0·007	0·25	2·58	0·20	0·17	0·14	—	—	0·008	Nitrided	—	—	—	897–920	370–380	Outside 0·012 Inside 0·013	Abnormal
257	B.M.W. 801 G ..	0·31	0·255	0·64	0·013	0·007	0·22	2·63	0·08	0·21	0·16	—	—	0·009	Nitrided	—	—	—	700–775	325	Outside 0·013 Inside 0·014	—
268	B.M.W. 801 G2	0·29	0·36	0·57	0·009	0·008	0·23	2·65	Tr.	0·16	—	—	—	—	Nitrided	—	—	—	743–772	—	Outside 0·012 Inside 0·011	—

Correspondence

The Elastic Limit

To the Editor, METALLURGIA.

Sir,

You have no doubt already acquainted Dr. Vivian with the special circumstances in which your usual admirable procedure for once failed to function, with the result that I did not become aware of his letter of the 5th September until I received the September issue of your journal in the ordinary course; and he will therefore appreciate that the delay in dealing with his interesting communication has not involved any discourtesy on my part.*

I was a little surprised to learn that a few thoughts designed to help in assembling our fascinating jig-saw had exposed me, in Dr. Vivian's opinion, to two charges: first, that I had misrepresented his views; and second, that I had succumbed to the allurement of over-simplication.

That I am not guilty on the first count seems to be clearly shown by Dr. Vivian's own insistence that he has invariably taught that "literal elastic limits cannot be expected in . . . . . aggregates which are not single crystals." That is precisely the interpretation of Dr. Vivian's views that I had in mind when writing my letter of the 31st August, in which I simply called attention to the important experimental evidence which has proved that "literal elastic limits" can in fact be readily observed in certain polycrystalline aggregates, which is exactly what Dr. Vivian seeks most emphatically to deny. It is now relevant to add that current experimental difficulties in detecting the existence of similar limits in all such aggregates cannot properly be construed as proof that they do not generally exist or tend to exist (Smith and Wood: *Proc. Roy. Soc.*, 1941, vol. 178, p. 104).

The second charge is one that I am normally disposed to invite rather than to avoid. I believe that the history of science teaches us to mistrust the complex, and that Newton was very wise when he wrote that "Nature is pleased with simplicity, and affects not the pomp of superfluous causes." In the present case, however, I certainly regarded Dr. Vivian's apparent oversight of some vital pieces of our "tantalising" jig-saw as indicating that this particular boot was really on the other foot. On the other hand, and in the light of the wide range of factual evidence already available, I can see but little reason for over-complicating our problem by introducing the conception that single crystals are "critically different" from polycrystalline aggregates. I undoubtedly prefer the apparently simpler view that, in polycrystals, whatever may be the quantitative effects of major structural boundaries on the externally measured characteristics of the aggregate, they are qualitatively just as "extraneous" to the basic behaviour of the ordered regions of the lattice as are the effects of small percentages of "foreign' atoms (such as carbon in iron). The highly structure-sensitive phenomena of ferromagnetism would appear to lend considerable support to this latter view.

There is one point on which Dr. Vivian has obviously misread me. When I referred to Hook's Law as being "quite decently observed," I was dealing solely with the internal elastic behaviour of the ordered regions of the lattice, whereas the electron micrometer measurements necessarily cover the external behaviour of the specimen as a whole; and, as I have previously argued there is every reason for believing that such external measurements even when made within the so-called "elastic range" may easily include a component of irreversible deformation with which the "internal" X-ray evidence is not concerned. Moreover it does not seem unreasonable to suggest that within the same range, an element of irreversible deformation may also occur in the disordered regions of so-called "single crystals" but whether such deformation is measurable or not would seem to depend entirely on the sensitivity of our methods of assessment. It has, however, already been considered justifiable to make the general statement that "careful measurements indicate that a small and gradual plastic flow occurs in single crystals of metals at arbitrarily small values of the stress." (Seitz: "*Physics of Metals.*" Mc-Graw-Hill, 1943, p. 77. For typical original work, see also Chalmers: *Proc. Roy. Soc.*, 1936, vol. 156, p. 427). We may still have much to learn about low-temperature "creep," but what we already know would appear to oppose Dr. Vivian's view that during the early stages of mechanical deformation, with which we are here primarily concerned, the behaviour of single crystals is "critically different" from that of polycrystalline aggregates.

I am, Sir,

Yours faithfully,

(signed) G. C. RICHER.

Newport, Mon.
September 29, 1945.

* In normal circumstances Mr. Richer would have received a copy of Dr. Vivian's comments before they were published in our September issue, but he was on holiday and, although he was good enough to send us his holiday address, we did not wish to disturb his recreation with some complexities of the elastic limit.—Editor.

Effect of Various Surface and Structural Conditions on Nitriding

To the Editor METALLURGIA.

Sir

We were very interested to see the article in your August issue, under the above title, giving the results of various experiments carried out by the author, Mr. F. F. Dodson, on the nitriding of steels to Specifications D.T.D. 87A and D.T.D. 306.

As these results are at variance with those obtained by the users of our Nitriding Process and with the standard practice laid down by us for the guidance of our Licencees, we would appreciate your publishing the following comments on Mr. Dodson's article :

Paragraph 1. We do not agree that it is a " widely accepted statement " that defects in a nitride case are due either to grease from handling or to the oxide film produced owing to the container not having been purged. In actual fact, these are the least serious forms of surface contamination which may be encountered. Finger grease has been ignored by us, except in the very early initial experiments, whilst the oxide film, produced during the heating-up period, is negligible and is very quickly reduced by the hydrogen present in the box.

Experiment No. 1. The types of oxide film, produced as enumerated, would certainly have no detrimental effect on a nitride case. The surface, which is most undesirable, is the type produced by hot rolling or forging, when a heavy oxide scale may be formed and worked into the surface of the metal. Such a scale may prevent the surface being nitrided at all and in any event, the depth and hardness of the nitride case, under such a scale, would be far below standard. Moreover, the presence of large areas of such scale in a nitriding charge would seriously upset the ammonia dissociation, to the detriment of the remainder of the charge.

Experiment No. 2. This paragraph infers that degreasing is merely a waste of time and materials. We maintain that cleanliness is conducive to the production of a good article and it is quite certain that, if the author were to charge a furnace with the kind of parts, which an area nitriding Licencee is liable to receive, that is, coated with anything from tallow to varnish, he would very quickly run into serious trouble, unless he first degreased them.

One of the main reasons for degreasing, prior to charging for nitriding, is to prevent the exhaust pipe of the nitriding box becoming blocked with soot and partly burnt grease. Any such blockages are most troublesome, particularly when the boxes are fitted with powder seals.

Experiment No. 3. We agree that purging is an unnecessary waste of time, and it has never been adopted as standard practice. If gas is admitted to the nitriding container when it is charged into a hot furnace, purging will take place during the heating up period.

We consider that the time of 1¼ hours, given by the author for reaching 500° C., is rather too short, as there would then be a danger of overheating that portion of the charge nearest to the furnace elements. We should prefer 4 to 5 hours for the size of container specified.

Experiment No. 4. We should anticipate unfavourable comment from customers, if they received nitrided parts from us with a " blackleaded " finish, instead of the usual grey matt finish given by successful nitriding. It is, therefore, worth while to spend a little time in degreasing from this commercial aspect, apart from any other considerations.

Experiment No. 5. We have no actual experience on the nitriding of burnished surfaces, but we maintain that such a surface is less responsive to nitriding than a normal machined or ground surface. This is certainly true when dealing with austenitic materials and, also, with cold-drawn surfaces.

Comparison of methods of carrying out the Nitriding Process. The author seems to have made out a good case for the " Unorthodox Method." It is certainly unorthodox, inasmuch as it allows 5 hours to tin 100 components and 1 hour to clean them. By our methods, tinning would require 1 hour and cleaning 10 minutes. The whole process, using the high input furnace as described by the author, would take 23 hours 55 minutes by our orthodox method as against 26 hours 55 minutes by the author's unorthodox method.

Comments. Soft spots, or rather soft portions of a charge, can certainly be produced by allowing stagnant pockets of gas to form in the container. In our recent instructional booklet to our Licencees, we say " This range of 25% to 30% dissociation only holds good when dealing with a normally full nitriding container. If a large container is used for nitriding a few parts, which only require a small amount of ammonia gas to maintain a dissociation of 30%, very little circulation of gas will take place inside the container and around the articles to be nitrided. This will result in partial stagnation of the container atmosphere, with possible pockets of high hydrogen concentration which will result, in turn, in a shallow nitride case, or in patchy hardness or in a total absence of hardening. When dealing with such charges, therefore, it is essential to use plenty of ammonia in order to create turbulence around the articles, ignoring the figure of 25% to 30% recommended, in favour of a figure of 10% or less. The amount of gas flow will depend, of course, on the relative sizes of charge and container but the object to be attained is to keep the charge supplied with fresh ammonia and to create a flow sufficiently strong to sweep out all unwanted hydrogen."

The author's final statement that nitriding is possible regardless of the surface condition is too sweeping. Nitriding is not possible when the surface of the steel is decarburised or possesses a thick oxide scale. Corrosion pits are also dangerous as these produce discontinuity of the nitride case, resulting in areas of potential failure in any high precision article. Moreover, the carbonaceous matter in decomposed grease is often converted into ammonium carbonate, which adds further to the danger of blocked pipes.

Yours faithfully,

NITRALLOY LIMITED.

(signed) R. W. Allott,

Director.

25, Taptonville Road,
Sheffield, 10.
September 24, 1945.

To the Editor, METALLURGIA.

Sir—I thank you for sending me a copy of Mr. Allott's comments on my report of some experiments I carried out on D.T.D. 87A and D.T.D. 306 nitriding steels, which was published in your August issue.

May I point out that my work was purely experimental and that all surface conditions were accentuated for a specific purpose, and not as a suggested practice.

However, it seems advantageous to reply to his comments in sequence.

Paragraph 1. My phrase "widely accepted statement" was considered concise, and certainly is a fact. Having controlled various plants and discussed nitriding with technicians from many parts of England, it became obvious to me that they were of the opinion that for satisfactory results, care should be taken to ensure that all stock to be nitrided is chemically clean and that the "seal" of the container should not "blow" during the process to admit air. Mr. Allott admits finger grease was once suspected in the early stages, and, whatever the advice given to Licencees of these findings, the opinion still holds.

Experiment No. 1. The comments agree with my findings regarding oxide films and adds that a surface that has been hot rolled or forged is most undesirable. Surely no firm would attempt to nitride components without first heat treating e.g. harden and temper, rough machine (which would remove such an undesirable surface) heat treat (stabilise) and finally light machine to required dimensions. Should, however, large areas of scale be present in a load of nitriding, Mr. Allott maintains that the dissociation would be seriously upset, to the extent of affecting the remainder of the charge. Whilst it is obvious that the dissociation would be altered (increased) I have found that providing a good turbulence of gas is maintained around the stock, the dissociation can be allowed to increase to 50% without any ill effects. I experimented with various high dissociations after reading of some work done in America on the subject, the materials I used being D.T.D. 87A and D.T.D. 306. Plants fitted with fans for circulating the gas are more suitable for operating high dissociation.

Experiment No. 2. This experiment was carried out to find the effect of nitriding steel with a greasy surface. The conditions were greatly exaggerated as I considered that if satisfactory results could be obtained by such drastic methods, then finger grease marks transferred to components whilst handling after plating, would be of no consequence, therefore degreasing would not be necessary. Probably I should have made my article a little more clear on this fact. I certainly agree that if components received were covered with tallow or varnish they would need degreasing from a commonsense point of view, as an explosion would soon occur if such work was processed.

Experiment No. 3. I have not found any evidence of overheating of components or containers, through rapid heating.

Experiment No. 4. I consider the comments irrelevant as I did not suggest that articles be greased before nitriding as a production load, but merely remarked on the black leaded appearance of articles after the experimental process.

Experiment No. 5. I would state again that the report only referred to D.T.D. 87A and 306 materials, and that a burnished finish or surface did not restrict or influence the nitriding whatsoever.

Comparison of Methods of carrying out the nitriding process. Mr. Allott states that the time allowed for plating 100 components e.g. 5 hours, to be excessive and adds that one hour would suffice. However the particular components were of intricate design and had to be efficiently "stopped off" in various areas; this needed close supervision. I did not claim any time saved due to plating, but in the cleaning after plating as in the orthodox method, each component was degreased and individually wiped before loading into container; whilst in the unorthodox method they were loaded directly into the container after the last plating operation, which was drying. Therefore, I claimed time saved thus, in cleaning, purging, heating to temperature and cooling. I would take this opportunity to answer the Editor's footnote query on the latter item of cooling. This was "Surely this could be applied to the orthodox method." I certainly agree that this could be done, but then the orthodox method would become unorthodox, as I do not know of any other firm using such a method of cooling.

Comments. I must admit that my statement, that nitriding is possible regardless of surface conditions is misleading for anyone without knowledge on the subject of nitriding. But if read as it should be, in conjunction with the report, it is plain to see that I refer to oxide films and grease that had been applied to a prepared surface. However, summing up, I think the point at issue is simply this "is it a widely accepted statement that defects in the nitrided case can be caused by oxidation or greasy areas on the surface of the steel being processed?" Knowing that technical representatives of one of the country's largest furnace manufacturers, who instal and instruct personnel in the process are of this opinion, I know that it is a widely circulated statement.

Yours faithfully,

Acocks Green, Birmingham.
October 2, 1945.

FREDERICK F. DODSON.

Forthcoming Meetings

Joint Meeting

Oct. 24. Joint meeting of Manchester Metallurgical Society, the Institute of Metals, and the Iron and Steel Institute, at the Engineers' Club, Albert Square, Manchester.
Dr. W. T. GRIFFITHS, President of the Institute of Metals, will occupy the Chair (6-30 p.m.).
Dr. R. JACKSON will lecture on "The Application of Radiography to the Improvement of Foundry Technique."

West of Scotland Iron and Steel Institute

Nov. 9. "The Making of Manganese Steel Castings by Continuous Process," by C. J. DADSWELL, B.Sc., Ph.D.

Institute of Engineers and Shipbuilders in Scotland

Nov. 6. "Theory of Forging Hammers and their Foundations," by W. C. ANDREWS and J. H. A. CROCKETT, B.Sc.

Sheffield Metallurgical Association

Oct. 30. "Furnace Automatic Control," by A. MUIR.
Nov. 13. "Technical and Economic Problems in the Heavy Iron and Steel Industry," by R. A. HACKING, M.Sc.

Institution of Mechanical Engineers

Oct. 26. "The Mechanism of Tool Vibration in the Cutting of Steel," by Prof. R. N. ARNOLD, D.Sc., M.I.Mech.E.
Nov. 9. "Elementary Principles of Plant Organisation and Maintenance for Civil Engineering Contractors," by H. O. PARRACK, A.M.I. Mech.E.

The Coinage Metals in Antiquity

Part V.—Aegean and Offshoot Cultures; Cloisonné

By Douglas Rennie Hudson, B.Sc., Ph.D.

(Lecturer in Metallurgy, University of Leeds).

"Aufgebaut auf kostbarer Unterlage, geschmückt mit den sieben Samtfarben des Regenbogens, die durch Zufälle aus Luft und Feuer vervielfacht werden, von goldenen Linien durchzogen wie die Mamma von blauen Adern, schimmernd und schillernd, mit einem Glanz, der ungeschaute Tiefen aufhellt, wird ein Juwel geschaffen, grösser als der Diamant und von kristallinischem Glanz, mit der Glut der Rubin, den Eisblumen des Smaragd, und den sonnendurchleuchteten Wolken des Opal."

"Built up on costly substrates, decorated with all seven colours of the rainbow, which are multiplied by accident of atmosphere and fire, penetrated by gold lines as the breast by blue veins, shimmering and iridescent, with a lustre that lightens undisclosed depths, a jewel is created, greater than the diamond and of crystalline lustre, with the glow of the ruby, the rime-flowers of the emerald, and the sun-irradiated clouds of the opal."

M. Rosenberg, 1922.

ABSTRACT

A critical review of the growth of metal working in the Aegean cultures under the heads:—

1. The Greek Mainland.—*Cyclades Islands, Tiryns, Mykenæ.*
2. —Greek Gold Cups.—*Vapheio Bull Hunt Cups, Midea Octopus Cups;* Hellenic beaten gold work probably not of Cretan origin, *Aegean products in Egyptian Murals, 15th Century, B.C., Metalwork probably of Mainland and not Cretan origin;* The malign harvest of Aristotle.
3. Metal Enamelling.—*Old British Enamels, Techniques.*
4. Diffusion of Influence from Greek Colonies.—*North of the Black Sea, Western Mediterranean Littoral, Constantinople.*
5. Crux cum septem mysteriis Jesu Christi.
6. The Traprain Silver Hoard.
7. Duke Tassilo's Chalice at Kremsmünster.
8. The Cup of St. Agnes' Martyrdom.

Aegean and derivative cultures cannot be treated *en bloc* on account of the many cultural cross currents, individual examples are therefore discussed. The author proposes that fine *repoussé* gold works of Greece (e.g., the bull hunt cups of Vapheio and the octopus cups of Midea) were actually mainland products and not imports from Crete as is commonly supposed. Those depicted in factors' tomb paintings in Egyptian Thebes c. 1500 B.C., together with rhytons, were doubtless obtained as plunder or trade goods by the ambassadors. Ethnically and by dress these are clearly Minoans and Syrians, at this time the Minoans were daring sailors and probably accomplished pirates.

Enamel work, illustrated in two colour plates, reached high perfection amongst the Ancient Britons about the time of Christ, and spread to Ireland, where the fine metal tradition formed the basis of stone carvings and book illumination, just as the Cretan potter copied metal vases, this *Scotic Cloisonné* is characterised by orange-red spots. In Constantinople about a millennium later another peak occurred, this has given its name to the careful finished, sophisticated enamels called Byzantine.

In previous sections it has been possible to examine cultures, which, if not homogeneous in nature and time, are at least coherent within the area considered. But in the Central Mediterranean the currents of diffusion are confused and it is correspondingly more difficult to treat the material in continuous narrative.

As an example the eminent Mediterranean archaeologist Hall states: "The remains of the Neolithic period in Greece are usually sparse and disconnected. While in Crete and in Northern Greece we have evidence of a long period of neolithic occupation and development, and there is distinct evidence of neolithic inhabitance of the Peloponnese, in Cyprus there is hardly any trace of neolithic culture, and in the Cyclades absolutely none. In fact whatever we may think of Cyprus there is little doubt that in purely neolithic days the southern Aegean islands were not inhabited at all. The Copper Age begins in the islands without preface and we can have little doubt that its inception in them marks the beginning of their occupation by colonists from Anatolia and Crete, hardly earlier than 3000 B.C. . . . In Thessaly the local culture passed from the neolithic to the metal-using stage, apparently without experiencing conquest from the south." Here a native northern Greek civilisation persisted for centuries without using metal. Its fine hand-made pottery with cross hatchings and comb designs was originally self-red showing progressively—white lines, and red on a white slip. Eventually at EM II-III, with the use of metal, northern invaders introduced geometric designs in brown/black, buff and even orange. Moreover there now appears the first spiral which may be prototypical of of Keltic ornament.

In proceeding northwards and westwards from Greece,

to follow the stream of diffusion, and in the meantime entering historical time when the material available greatly increases, we find the patchiness much accentuated. It is therefore necessary to examine individual facets of metal cultures, a method which is unsatisfactory because it is difficult to select artefacts typical of the civilisation concerned.

Fig. 38.—The King's cup from Midea, on the Greek mainland, circa 1500 B.C., discovered by Persson 1926/27.

12. THE GREEK MAINLAND

Greek civilisation did not reach a uniform level, but consisted rather of isolated islands in a primitive wilderness. At the end of Middle Minoan II, there was some sudden catastrophe in Knossos, which led to the eclipse of the brilliant, if cruel, Minoan civilization. However, this persisted in daughter cultures established in the mainland. The archæologist is able to correlate the *early*, *middle*, and *late* periods, approximately as follows :

	Crete (Minoan)	Greek Mainland (Helladic)	Cyclades (Cycladic)	Mykenæ (Mykenæan)
Early ..	2800–2200	2800(?)–2100(?)	2800–2200	2100–1500
Middle	2200–1600	2100(?)–1600	2200–1700	—
Late ..	1600–1100	1600–1100	1700–1100	1500–1100

Each period is sub-divided into three parts, which may be further split (e.g., to MM I*b*) as data accumulate.

Cyclades Islands.—The Cyclades culture was approximately contemporary with the Minoan. There are indigenous deposits of ores of copper, as a result this came into use at an early date, but silver, gold and lead were imported. Bronze was used in tools, weapons and vessels as early as 2500, from about 1400 B.C. the influence of Mykenæ was strong. These islands were very important as stepping stones between Anatolia and Thessalay. They produced the fine Minyan pottery in yellow and other colours.

Tiryns.—In its wall paintings the culture resembles the Mykenæan, but probably of later date. Lead was used extensively in clamps, vases and jars, and other utilitarian objects. Gold was abundant and silver artifacts have also been unearthed. Bronze of the standard composition, approximately 11 parts per cent. of tin, has been recovered in quantity. Note the delightful colour harmonies in Fig. 40, fresco of a conventialised boar hunt.

Mykenæ.—The excavations of SCHLIEMANN resulted in a great variety of metal objects of first-rate artistic quality, amply justifying Homer's appellation "abounding in gold," to King Agamemnon's Town. Relations with the mother culture of Crete were always very close and it is likely that Minoan artificers, or at least a school strongly maintaining the island tradition, worked in the city. The apothesis of their splendid inlaid work (Fig. 39), termed "painting in metals," must have persisted or remained familiar down to Homer's day : "Clusters wrought fair in gold, the grapes were black, but the vines hung throughout on silver poles."—*Iliad*, 18. Many fine examples of this technique, showing a combination of good taste and craftsmanship, as high as in pre-dynastic Sumer, have come down to us. The summit was reached in ornamental dagger blades in bronze, undercut about 1 mm. deep, and inlaid with silver and gold plates, and black *niello*. Both polished and "oxidised" finish was used on silver, and the styles have a distinct Egyptian flavour, e.g., idealized lotus flowers, fox, panther or cheetah, flying duck and fish in meandering river. Fig. 43 shows a dirk with gold-plated hilt, decorated with *repoussé fleur de lys*. The flowers are repeated along the bronze blade, inlaid in pale electrum petals with golden anthers, reproducing the actual colours as far as possible. Some caution is necessary in accepting technical terms used by the distinguished archæologists

13. GREEK GOLD CUPS

In the production of embossed cups and rhytons from gold and silver sheet, Aegean smiths reached a magnificent acme about 1500 B.C.

Vapheio Bull Hunt Cups.—On two gold cups from Vapheio the *repoussé* design is dynamic, divided into three scenes in each case. On one cup bulls are driven forward into an enclosure where their progress is checked by a rope barrier fastened to two olive trees. Fig. 32 shows how a cow*girl* lassoos by the left hind leg a bull which has been decoyed by a tame cow. The shape is distinctive, and is depicted in friezes in the palace at

Fig. 39.—Dirk from Mykenæ, showing bronze blade, inlaid with silver, black niello and gold, in the technique called "painting in metals." The scene is Egyptian, with a cheetah hunting wild duck among the lotus flowers fringing a meandering river.

Knossos, in Crete. A bronze cup of similar form, smooth inside, with hollow ivy-leaf *Motiv* on the outside, almost certainly a *casting*, has been found in a Molchos burial. *The handle, too, is characteristic and has been copied, down to the very rivets, in other materials, e.g., a pottery cup from Nienhagen, in Silesia, and a veined stone cup from Knossos itself* (LM I*a*). Others are depicted as gifts from Keftiu (Crete) to Thotmes III (1501—1447 B.C.). It is clear, therefore, that the metal archetype goes back to MM II. In construction, the cups consist of the outer hammered sheet, lined with another smooth inner sheet, fastened at the rim. Note the exquisite treatment of the living subjects, the *élan* of the composition and the close attention to natural detail, without trace of stylism or Greek monumental conventions (Fig. 37, A and B). They were discovered in 1889 by TSOUNTAS, and are allocated to the 16th century B.C. With these were found a silver spoon and silver cups of graceful form, with bearded heads and flowers of gold and *niello* inlay, probably contemporaneous. In view of the typical Cretan style, it has been suggested that they were imported from the island, possibly *via* Mykenæ.

"Harvester," "Chieftain," and "Gladiator" vases, Haghia Triada, show attainment at least as high in black "steatite," (?) which may have been gilt, to resemble metal (*c.* 1600 B.C.).

Midea Octopus Cups.—In 1926-27, PERSSON recovered many fine metal objects from a *tholos* tomb, at Dendra, near Midea. They include an engraved seal ring, a silver goblet, with hunting scene (much damaged), bronze mountings for a wooden stoup and a cylindrical bronze box. Fig. 38 shows the king's cup in gold, attributed to 1500 B.C. "From a technical point of view the octopus cup is a perfect masterpiece, artistically it may seem, to our taste, perhaps a little over-loaded, but beyond all doubt it is a work of art of the first rank, and well deserves to be placed beside the famous Vapheio cups." The queen's cup consists of an outer sheet of silver, with bulls' heads inlaid in *niello* and gold, with an inner lining of gold sheet. Probably these two metals were attached by an intermediate bronze plate—a technique used by Mykenæ smiths. "The shape of the cup is that of the famous Vapheio cups, and these bulls are similar . . . the relief is not so high, but the execution is finer and more delicate." A date of 1400 B.C. is suggested.

Fig. 40.—Fresco from Tiryns, showing conventionalised boar-hunt (restored). Note the careful balance of the pattern, the confident pencil and the sophisticated colour harmonies. (*After Rodenwaldt*).

Hellenic Beaten Gold Work probably not of Cretan Origin

In this survey the author has re-stated, not without qualms, the orthodox archaeological view that these metal productions are "Minoan." Commonly this is taken to mean that they were produced in Crete and exported to Peloponnesus. It seems that this is nothing but gratuitous assumption without a single shred of evidence to support it. Certainly Minoan culture was very advanced, its *forte* being architecture and pottery, and to a less extent painting, shown clearly by the excavations at Knossos, Phaestos and Haghia Triada. We should not allow the brilliance of Cretan architecture to blind us in the *facile* assumption that fine cups like those from Vapheio and Midea (Figs. 37, 38) were imports from Crete, *although no similar cup has ever been found on the island, nor indeed any beaten metal-work even approaching such perfection, so far as the author is aware.* Moreover, frescoes at Tiryns are certainly not inferior to those of Knossos.

Further, the accomplished Minoan potter seems to have gilded in direct imitation of metal, for instance the fine "Harvester" vase. (This is by no means unique; beaked vases have been published—in gold, copper and alabaster, and silver, from Ur, Abydos, and Hissar, by WOOLLEY, PETRIE, and SCHMIDT, respectively.) Similarly he blended his glaze with the utmost care to simulate stone vases in red breccia. But more convincing evidence is available. Mrs. BOYD-HAWES has reported a most important find of two fragile thin pottery vases lying, together with the fluted silver original which they simulate, at Gournia in Eastern Crete. Fig. 42 shows a beaked vase in silver from Hissar.

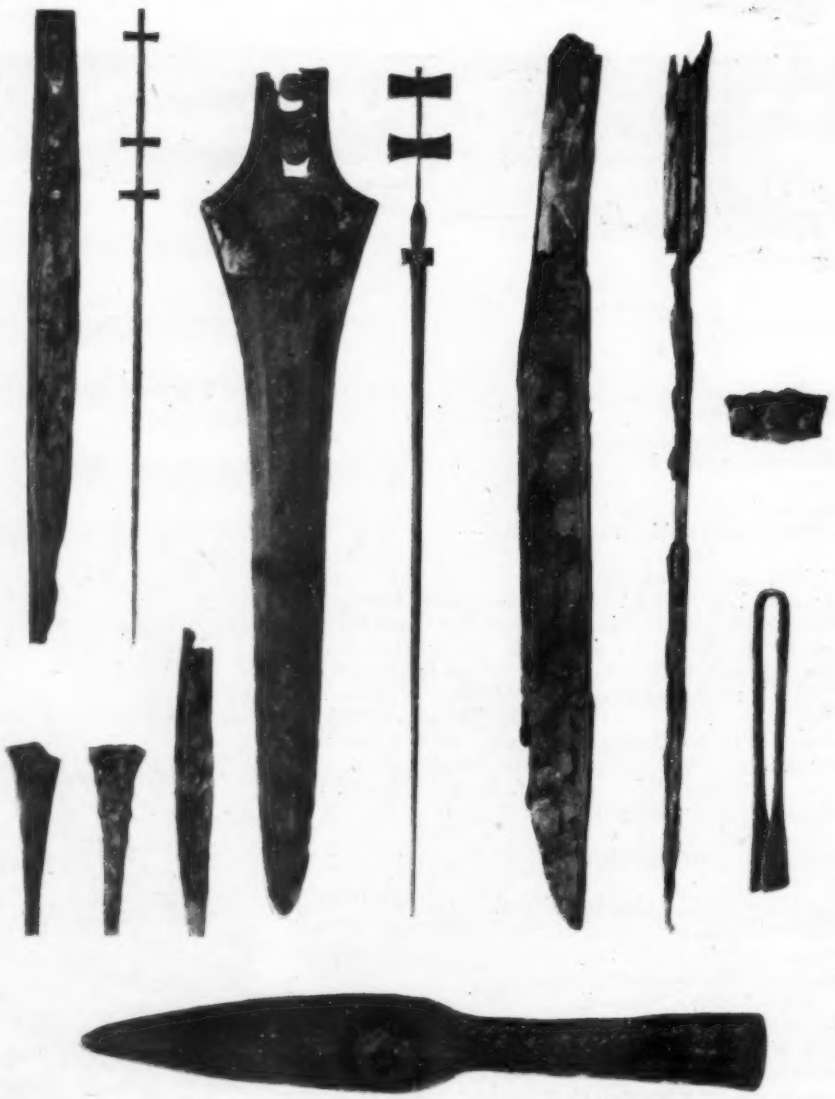


Fig. 41.—Mykenæ daggers and swords, illustrating stiffening midrib and rudimentary hilt. Corrosion of the metal has been serious. (*After Wace*).

Aegean products in Egyptian murals, 15th century B.C.—The reason for attributing such fine products as the bull-hunt and octopus cups from Hellas, to Crete, seems to be the wall paintings on the tombs of the Egyptian factors *c.* 1450 B.C., with the inscription that they represent messengers from "Keftiu and the islands in the great green." In the controversy over the location of Keftiu (Kaphtor)—whether Crete or Asia Minor—it would be improper as well as unprofitable for the author to engage.

"*Hypotheses non fingo.*"—ISAAC NEWTON.

To assume that Keftiu signified the Peloponnese would be a very useful peg in support of the present contention that the gold cups are of Mainland origin, and an assumption better justified than many. However, with the awful example of totally fallacious conclusions which distinguished excavators have drawn by misinterpretation of metallurgical and chemical evidence (for instance the great PEAKE'S trans-Carpathian gold in Egypt) we avoid this very attractive hypothesis for Keftiu or Kaphtor. Whether or no the identification is correct—and on this point not even the pre-historian

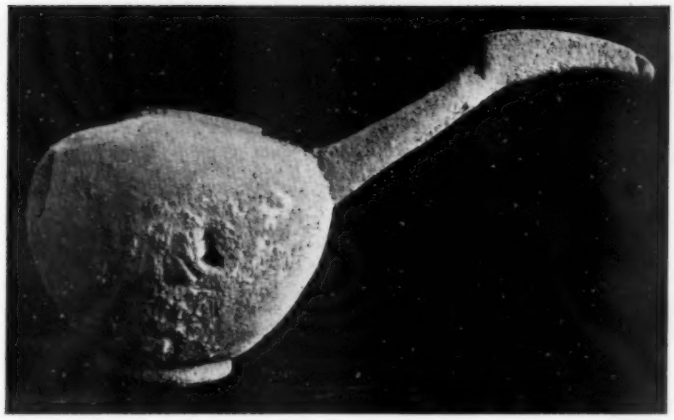


Fig. 42.—Beaked bowl in silver from Hissar III, pre-1500 B.C. (?). *After Schmidt.* Similar shapes have been reported from Ur (c. 3200 B.C.) by Woolley in gold, from Abydos (c. 3000 B.C.) by Petrie in copper and alabaster. In Crete the accomplished Minoan potters c. 2500 copied the Motiv in Vasiliki pottery and inserted rudimentary eyes and beak. The pattern is unpleasing to the artist and downright repugnant to the functionalist. Here is evidence for diffusion from Sumer via Anatolia.

can decide with authority—it is not necessary for the present proposal of Mainland origins for the cups. In coloured wall-paintings of ambassadors from the tomb of Rekhmara at Thebes (c. 1450 B.C.) Minoans, Syrians or Anatolians, Nubians and Ethiopians are easily identifiable from somatic characteristics and clothing, so accurately did the stilted Egyptian draftsman portray what he saw. (These Minoans do not show the wasp-waist of the Knossos frescoes, seals and statuettes.) As well as Vapheio cups and rhytons of conical and bull's head shape, they carry ox-hide copper ingots for synthesis of bronze in Egypt. *Certainly this copper was not produced in Crete.* In the fifteenth century B.C. the Minoans were daring and expert sailors, a euphemism for "singeing the King of Spain's beard." If such successful privateers could bring, as tribute or gift, copper ingots from producing areas far from their own island—from Sardinia or Cyprus—what was to prevent them from bringing gold cups and rhytons in beaten metal from the mainland close at hand?

Fig. 43.—Dirk from Mykenæ, with fleur de lys in relief (restored). The petals are of pale electrum and the anthers of gold, with a view to reproducing natural colours.

Metalwork probably of Mainland and not Cretan origin.—In brief it is proposed that this goldsmith's work derived not from Crete but from some centres of fine metal work on the mainland. Quite possibly these were satellite cultures and to that extent Minoan, but it is difficult to believe that these finished metal artefacts originated in the island. Nobody has suggested that the Black Sea Greek colonial cities imported metal objects from Crete, yet this would be quite as logical. Doubtless when excavation on the Mainland is as thorough as it has been on Crete, we shall learn more of these metal-working centres. The calamity which led to the collapse and desertion of Knossos is well known, and estimated at 1450-1400 B.C. Much of the beaten gold-work has been placed at 1600-1400 B.C. Probably an attempt to correlate the Minoan collapse with the *floruit* in Hellas would yield interesting results.

Fig. 44.—Bowl in gold from Palestrina, Central Italy. Compare with the fine repoussé in Figs. 37 and 38. Victoria and Albert Museum.

The Malign Harvest of Aristotle.

Here it is pertinent to enter a *caveat.* The wide and deep knowledge of classics fostered by "grammar" schools (from their study of Latin grammar) led to Greek and Roman science and technology being regarded as the fountain of modern achievement—a point of view supported by the fine achievements of Hellas in original philosophy, abstract geometry and political government. Never was credit so wholly unjustified. Greek technology in historical time was greatly inferior to the cultures of the Nile and Irak and others, to which it was heir;

of process metallurgy it seems to have been entirely ignorant. Even in the great tradition of metal working (Figs. 37, 38, 39, 43) to which it was direct successor, it fell far behind artistic standards attained a millennium before.

Fig. 45.—Enamel cross from the Lateran Chapel now in the Vatican Museum ; 7th century A.D. (?). Note the fine colour contrasts and the excellent workmanship. Basis metal unknown, weight 40 oz. troy.

Nobody can estimate what harm the dead hand of Aristotle, by contempt of base experiment as utterly beneath the noble attention of the speculative philosopher, has done to science through two thousand years. To-day the mood has past. Well may BERTRAND RUSSELL remark : " Aristotle, it should be said, has been one of the great misfortunes of the human race. To this day the teaching of logic in most universities is full of nonsense for which he is responsible."

14. METAL ENAMELLING

" . . . *the barbarians of the ocean pour these colours on heated bronze, and they adhere, become hard as stone and preserve the designs.*"—The Sophist PHILOSTRATUS, *c.* A.D. 200.

We now meet the new technique of metal enamelling, with all the glorious colours and contrasts which it made available to the craftsman, a novelty exploited to the full by Keltic artificers in Wales, Ireland and Europe, and by the Greeks at Constantinople and in South Russia. It requires neither art expert nor working jeweller to appreciate the fineness of such productions as the papal cross shown in Fig. 45, and ROSENBERG'S eulogy is no whit overdrawn. These enamels have always had a particular fascination for the layman, not merely the connoisseur but the rich patron not always endowed with good taste, possibly because of this very juxtaposition of brilliant colours. For the craftsman, too, the technique has a particular attraction on account of unpredictable variations of hue and tone which may occur from the oxidising or reducing atmosphere of the furnace, not only between different cells, but even within the paste in a single one. Similar variations add to the attraction of glazes on Chinese procelain.

Old British Enamels.—Where the technique was " invented " is not known, probably it was a gradual development—glazes were known in Egypt in the Old Kingdom, enamelled bricks in Babylon, the glazed bas-relief murals in Iran had reached high perfection by the fifth century B.C.

We can, however, easily recognise two peaks of attainment, in Wales about the time of Our Lord (an exact date is very difficult to estimate) and in Byzantium and daughter cultures about ten centuries later. " *No finer enamelling on bronze was done than that done in early Britain.*"

This is extremely astonishing ; who from Caesar's *De Bello Gallico* would credit the Ancient Britons with any technical attainment ? And where no question of Imperial or personal prestige is involved, his accounts are generally detailed and trustworthy. But it is no more surprising than the magnificent monastic *floruit* in Ireland, in the metal arts, jewellery, book illumination and the vigorous Christian mission, which shone bright as a lighthouse beam in the Dark Ages of Europe.

This was due, to some extent, to immigration from Wales of Ancient Britons fleeing before the Roman Conquest. (See also METALLURGIA, **31**, pp. 283-290, April, 1945 ; **32**, pp. 9-13, May, 1945.) Many years ago ALLEN proposed that the interlacing patterns found on stone crosses which abound in northern Europe, were derived from designs developed in Keltic metal working —citing vestigial bosses on wheel crosses as the remains of metal rivets in the original traditional patterns. In a critical survey (*ibid.*) the author has proposed that the fine interlacing patterns of manuscript illuminations, in which the Keltic artificers excelled with their fantastic geometric patterns of inter-twined contorted birds and hideous lizards, were also derived from metal work. In the same way, Minoan potters faithfully copied metal vases. He would *correlate the decoration with lines of red diamonds*, ubiquitous in early manuscripts, *with the spots of orange-red enamel*, so characteristic of Irish monastic enamel as to be used as a criterion of its

provenance (*ibid.* Figs. 5, 9). These *spots of red* which occur (to the exclusion of other colours) both in enamel and illumination, are believed to be in imitation of coral amulets. In the earlier British enamelling, white, yellow, and blue were also used, the peak of achievement was probably reached before A.D. 200 in Scotland and Wales. No doubt the bright colours were developed from glass ornaments and faience glazes; e.g., a silicate frit coloured with copper or cobalt was used in Ancient Egypt in simulation of *lapis lazuli* (Egyptian *Chesbet*), possibly the "burned" and "unburned" κυανος of Theophrastes refer to these. The older enamels were substantially opaque but by the thirteenth century Italian artificers had brought the production of transparent enamels to perfection. (See also Figs. 45, 46; and Fig. 9, *ibid.*)

Techniques.—Two techniques are distinguished. The cells may be separated by thin metal walls standing on the metal substrate, or hollows may be made in the surface of the substrate to hold the fusible paste; these are known respectively as *cloisonné* and *champlevé*. Some examples also occur in which the bright pastes are directly in contact, without separating metal walls, presumably in such work the different colours had also different flowing points; multiple firing with very carefully controlled muffle temperatures must have been used.

15. DIFFUSION OF INFLUENCE FROM GREEK COLONIES

With Greek colonisation, their goldsmiths' skill spread right through the Mediterranean area. Though the standard of workmanship remained high, there was a definite falling off from the apogee of 1500 B.C. so far as we can deduce.

North of the Black Sea.—In South Russia, where it penetrated from the Greek cities north of the Black Sea, and from the Dnieper and Don settlements, Hellenic style was profoundly modified by Scythian influence (Fig. 23) resulting in a very attractive South Russian hybrid (Figs. 24 and 25) of which many specimens were preserved in the Imperial Hermitage Museum at St. Petersburg.

Western Mediterranean Littoral.—Via *Magna Graecia*,

Fig. 46.—"The Royal Gold Cup," weight 79 oz. troy.—British Museum. Made about 1350 for the Duc de Berri probably in S. France, and subsequently modified for Henry VIII. Note the fine transparent enamels, brilliant colouring, delicate draftsmanship, and excellent balance in decoration. Despite the good state of preservation, its history of six centuries is well authenticated from inventories.—British Museum.

Hellenic tradition spread to the whole of the western Mediterranean. In the Italian Peninsula it formed the foundation of the later metal work of Rome, but development was not maintained and after the acme about A.D. 750, Italian craftsmanship sank back into the barbarism from which it had emerged by following the accomplished Greek (Byzantine ?) tradition. Fig. 44 shows a fine granulated chased bowl in gold recovered from Praeneste (ancient Palestrina) in Central Italy, now in the Victoria and Albert Museum. Development from the fine Greek style of *repoussé* sheet cups with smooth lining (Figs. 37, 38, 32) is clear, but their lively treatment of living subjects is transformed into severe conventionalised designs. Compare this bowl with a silver cup from the Solokha grave near the mouth of the Dniepr (Fig. 24) which shows the above-mentioned composite style resulting from Scythian influence on the colonial Greek craftsman. In districts where Roman or Greek Christianity became dominant we have the " knot and ribbon " pattern ubiquitously.

Fig. 47.—" The Royal Gold Cup " conjectured original form restored by READ.

Constantinople.—The great focus of Hellenic metal working and jewellery was undoubtedly Byzantium. By the 8th century A.D. craftsmanship there was at a higher level than anywhere in Europe, and much of the inspiration for the wonderful metalwork and painting in the cathedrals of Europe sprang directly from this source. Here was developed the tradition of careful, finished, florid, jewelled work, which has received the description Byzantine reaching a summit about the 11th century A.D. This school was essentially Greek in character and we credit it with great progress in development of *cloisonné*, i.e., enamelled jewellery in which fusible pastes are placed in discrete cells separated by metal walls, to be melted into vari-coloured enamels on firing. This art came to great perfection amongst Keltic (Ireland and Europe) and Greek (Byzantium) craftsmen; whether we should attribute its *invention* to Wales or Byzantium is not clear. The pre-eminence of the earliest Brythonic enamelling is certainly evidence for the former. Moreover, a little after A.D. 200 the sophist Philostratus wrote " . . . the barbarians of the ocean pour these colours on heated bronze, and they adhere, become hard as stone and preserve the designs . . ." About this time the standard of work in Wales was at its summit. Note also the sharp red/blue contrast in the Scotic metal cover of the Lindau Gospels, *circa* A.D. 900.

Persecutions instituted by Emperor Leo Isaurian about A.D. 726 continued for a century, and succeeded in expelling from Byzantium a stream of Greek artists who settled in many towns of Central Europe, to the enduring enrichment of our heritage, *e.g.*, the Treasuries at Reims, Trier, Metz and Aachen and the engraved ivories of St. Gall; the great papal craftsmanship centre at Avignon is well known.

To be continued.

Wrought Light Alloys and South Wales

NEGOTIATIONS for the purchase of the Gowerton (Waunarlwydd) factory near Swansea by Imperial Chemical Industries Ltd. from the Ministry of Aircraft Production have now been completed. This factory was constructed and operated by the Metals Division of I.C.I. on behalf of the Ministry of Aircraft Production for the manufacture of wrought light alloys required primarily for the Government's aircraft programme.

A Discussion on the Notch Impact Test and its Interpretations*

By A. Fisher

Deputy Chief Metallurgist, Magnesium Elektron, Ltd.

Standard tests continue to be used to determine the relative suitability of different materials for service, but differences of opinion exist regarding these standard tests. One of the most contentious is the impact test, and in this article the author discusses some of the obstacles which have prevented much progress towards rationalising design methods for notched components; suggestions are made regarding testing methods and analyses of results; and a new formula is given which is claimed to provide a rational interpretation and expression of "notch sensitivity."

Notch Sensitivity—Methods of Comparison

The exact interpretation to be given to the term "notch sensitivity" is not yet universally agreed, and as data accumulates, earlier ideas tend to become somewhat modified. The impression is still widely prevalent, however, that notch sensitivity is a characteristic or fixed property of materials and that once a value for a given material has been determined in some way then the material can be appropriately labelled and the value obtained can be quoted as attaching permanently to the material, just as if notch sensitivity were a fundamental property like density or specific heat. Actually, the effect of a notch on the strength of a given material depends on many variables and the notch sensitivity may in consequence vary considerably; as indicated earlier, it may be positive, weakening the material, or negative, strengthening it.

Changes in strength on notching tensile specimens vary out of proportion to changes in the size of the notch, in many materials. As the notch depth is increased, the strength usually first falls, then after passing through a minimum for a certain critical size, rises again, sometimes above the original strength. Thus in the one material and in the same form of test, the notch sensitivity may be positive or negative, depending on the size of the notch. In some materials the strength falls continuously with increase in notch size, in others it rises continuously, Fig. 3. Obviously, notch sensitivity values are meaningless unless the size of notch and conditions of test are quoted, and a given material can not be labelled "notch-sensitive" in the sense that it is sensitive under all conditions of testing or loading.

Some general understanding then should be reached as to the engineering and metallurgical meaning of the expression. At present there is no such understanding. If "notch sensitivity" means sensitivity to a notch from the point of view of influence on strength, then it would seem immediately to be logical to define it as relative loss of strength, fractionally or as a percentage. For example, if the unnotched strength of a given specimen is 10 T.S.I. and the notched strength 7 T.S.I., that *specimen* could be said to be sensitive to the notch to the extent of 0·3, or 30% of the original strength. For general comparison purposes the use of a standard notch is, of course, essential, and with such a notch the percentage strength reduction on any representative specimen could be considered as a measure of the notch sensitivity of the material itself, i.e., for the purpose of comparison with other materials. For the reasons described above, the notch sensitivity values so calculated and the derived notch sensitivity ratios (i.e., of one material to another) can only strictly apply for the standardised notch, and may be quite different for other different sizes or shapes of notch.

This basis of percentage loss in strength when using one standard notch, would seem to provide a commonsense interpretation of "notch sensitivity," and it is in this sense of comparative loss of actual strength on standard specimens that most engineers will understand the term. For example, a given material "A," which showed an unnotched strength of 10 T.S.I. and a notched strength of 4 T.S.I. (60% loss) would be considered twice as sensitive to a notch as another material "B," which had the same unnotched strength but a notched strength of 7 T.S.I. (loss=30%).

Expressed as a formula, on this basis the notch sensitivity would be :—

$$\text{Notch sensitivity of specimen} = \frac{\text{loss of strength}}{\text{original strength (unnotched)}} = \frac{\text{original strength—strength as notched}}{\text{original strength}} = \frac{1\text{—strength as notched}}{\text{original strength}} \quad (1)$$

and in the above examples :—

$$\text{Notch sensitivity, (A)} = 1 - \frac{4}{10} = 0{\cdot}6 \text{ or } 60\%$$

$$\text{,, ,, (B)} = 1 - \frac{7}{10} = 0{\cdot}3 \text{ or } 30\%$$

This is one method of expression which has been occasionally used in the past.

There is, however, another basis of comparison which might be used, in which the loss of strength of the material tested is compared with the loss of strength of an ideal material which has full sensitivity to a notch, i.e., where the actual stress concentration at the breaking point corresponds with that calculated by the theory of elasticity. (It has to be assumed here that any material which has full sensitivity is perfectly elastic in the sense of proportionality of stress to strain, right up to the breaking point: the assumption is probably justifiable). This method should give results differing from the foregoing only in that the scale is changed so that the ideal material may have its notch sensitivity value

* Continued from September Issue page 198.

expressed as 1·0 or 100% ; the ratio of notch sensitivity of different materials, one to another, should not change. The method is developed in formula form below.

If with the same notch as in " A " and " B " above, the theoretical loss in strength of the fully notch sensitive material were 80%, corresponding to the stress concentration factor of 5·0, then the notch sensitivity of material " A " (60% loss) would be rated 60/80 × 1·0 = 0·75 or 75%. The sensitivity of material " B " (30% loss) would be 30/80 × 1·0 = 0·375 or 37½%. On this basis therefore, not only is the relative sensitivity—i.e., the ratio of one to the other, correctly expressible, but so also is the absolute sensitivity, in terms of the percentage of maximum sensitivity.

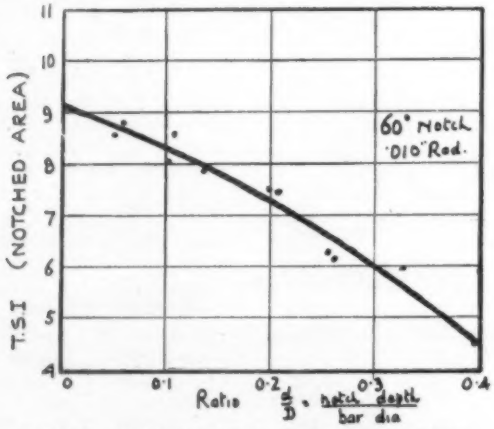


Fig. 6. Notch sensitivity curve for Elektron AZ.91., in static tension.

Expressed as a formula, the notch sensitivity on this basis would be :—

$$\text{Notch sensitivity} = \frac{\text{loss of strength of actual material}}{\text{loss of strength of ideal material}}$$

$$= \frac{\text{strength unnotched—strength notched}}{\text{strength unnotched—strength unnotched}}$$

$$\text{stress concentration factor}$$

The ratio of strength unnotched to strength notched has been named " notch effect index " by Buchmann, and adopting this term, the above formula may be written :—

$$\text{Notch sensitivity} = \frac{1 - \dfrac{1}{\text{notch effect index}}}{1 - \dfrac{1}{\text{stress concentration factor}}} \quad (2)$$

This method would thus seem to be the most desirable one to adopt. It enables both the relative and the absolute sensitivity values for different materials to be calculated from the test results when the same notch is used for each series of tests and the theoretical stress concentration factors are known. (There are already in existence certain tables and charts giving stress concentration factors for standard specimen and notch shapes and methods of stressing).[23, 24, 25, 26, 27, 28]

It does not seem that either this or any other method can be used to calculate comparative or relative notch sensitivity values when notches of different sizes are used on the specimens to be compared, for the reason already stated, namely, that the notch sensitivity of a given material varies with the size and shape of notch. If the shapes of the notch sensitivity value curves were the same for the two materials it might be possible, but not otherwise. There is great variety in these curve shapes, however, as will be seen from Fig. 3.

Perhaps an example will make the matter clear. Figs. 6 and 7 represent the notch sensitivity curves for Elektron AZ.91 and Melclif A.5 respectively, when ¾ in. dia. bars are tested statically in tension. Using (*a*) a 60° notch of depth equal to 0·05 of the diameter, the percentage reduction in strength on A.5 is 25% and on AZ.91, 5½%. With this notch therefore, A.5 is more than four times as sensitive as AZ.91. Using (*b*) a notch depth of 0·25 of the diameter, the percentage reduction in strength of AZ.91 is 27% but of A.5 is 11% *less than*

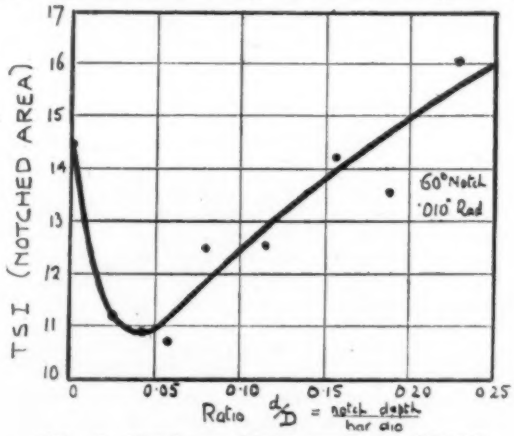


Fig. 7. Notch sensitivity curve for Melclif A.5., in static tension.

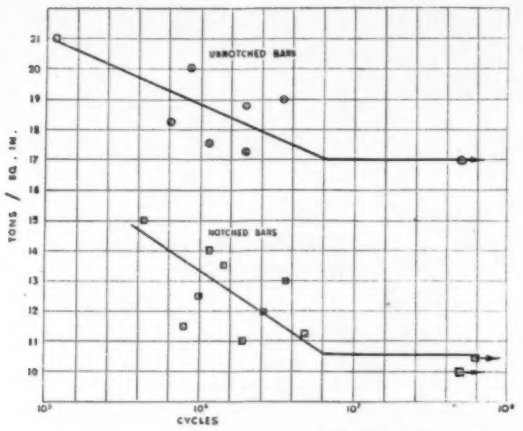
zero, i.e., there is an increase in strength ; thus the order of notch sensitivity is reversed. Had an attempt been made to compare A.5 with notch " a " against AZ.91 with notch " b " the sensitivities would appear approximately the same, 25% against 27% loss : alternatively, if A.5 with notch " b " were compared against AZ.91 with notch " a " the result would have been—A.5, 11% increase—AZ.91, 5½% decrease.

This example will make it clear that not only is it quite useless to compare results from specimens with different sized notches but a true picture can be obtained only when sufficient series of tests are made to enable sensitivities to be compared for all sizes of notch, i.e., when the complete curves are drawn and compared.

A tendency is occasionally observed to regard materials which have a low notched strength as being notch-sensitive materials, and those having a good notched strength as notch insensitive, irrespective of the unnotched strength. For example, mild steel is not often thought of as a notch-sensitive material, but in either impact or " static " bending tests on this material the loss of strength when notched as in an Izod specimen can be as much as 75%. As the residual strength (i.e., as notched) is still not low in comparison with other materials, its high notch sensitivity under these methods of loading is not generally realised. In comparison, magnesium alloys, which show a less loss of strength under the same conditions, have for some reason become labelled as notch sensitive. The same comparison can be made with regard to notch sensitivity in fatigue, see attached diagrams, Figs. 8, 9, 10 and 11. It is obviously important that in quoting figures for notch sensitivity

Test specimen machined from 1in. dia. rolled bar. Test specimen 0·400 in. dia. Semi-circular notch 0·047 in. radius.

Composition %.					
C	...	0·21	P	... ...	0·02
S	...	0·018	Mn	... ...	0·80
Fe remainder.					



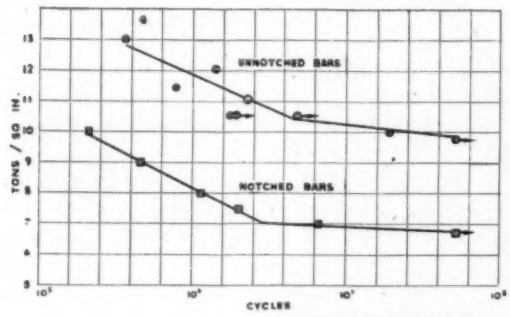
Static Tensile Test Results.
Average of 3 or more tests from the same material.

		0·1% P.S.	U.T.S.	Elong.
Fisher's N.S. Index ...	=0·88	Tons/sq. in.	Tons/sq. in.	% on 2 in.
Buchmann's N.S. Index	=0·81	23·0	36·2	32·5

Fig. 8. Wohler fatigue test results on mild steel.

Test pieces prepared from positions midway between butt and tip of blade. Test specimen 0·400 in. dia. Semi-circular notch 0·047 in. radius.

Composition %.					
Mn	...	0·59	Mg	... ...	0·66
Si	...	0·46	Cu	... ...	4·65
Fe	...	0·51	Ni	... ...	Nil.
Al remainder.					



Static Tensile Test Results.
Average of two or more tests from same material.

		0·1% P.S.	U.T.S.	Elong.
Fisher's N.S. Index ...	=0·73	Tons/sq. in.	Tons/sq. in.	% on 2 in.
Buchmann's N.S. Index	=0·61	18·5	29·5	17·0

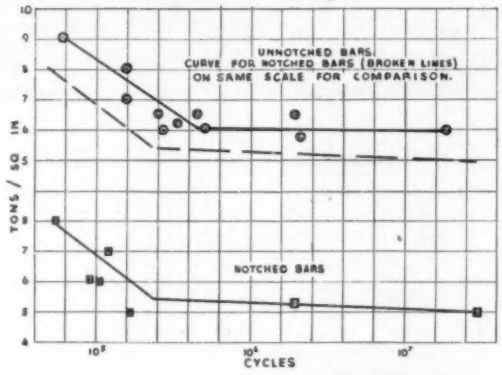
Fig. 9. Wohler fatigue test results on forged Duralumin.

the true meaning of the term be retained, i.e., as a comparison between the strength as notched and as unnotched, and that materials should not be labelled as notch sensitive or notch insensitive on a basis of notched strength only. Certainly the property which interests the engineer is the actual strength as notched, but the relative notch sensitivities of different materials cannot be compared or estimated by their notched strength alone, and the term should not be used on this basis.

It is desirable at this point to refer to a method of estimating and expressing notch sensitivity values, which has been much used amongst stress research workers in Germany and U.S.A., but which is definitely incorrect. This method was apparently originated by Thum and Buchmann[29] in 1932 and has been used by Peterson[26] and Peterson and Wahl.[25] Buchmann's terminology is :—

Test specimens machined from D.T.D. sand cast test bars. Heat-treatment : 8 hrs. at 395° C., 16 hrs. at 420° C. Semi-circular notch 0·047 in. radius.
Endurance values given in "Technology of Magnesium" for sand cast and solution treated Elektron AZ.91.
Unnotched ± 6·3 tons/sq. in.
Notched ... ... None given

Composition %.					
Al	...	9·5	Mn	... ...	0·3
Zn	...	0·4	Mg	... remainder	



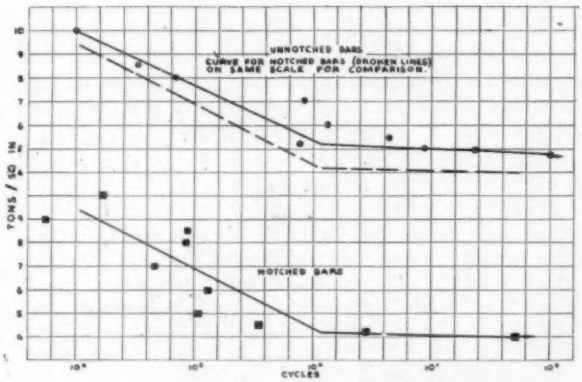
Static Tensile Test Results.
Average of 3 or more tests.

		0·1% P.S.	U.T.S.	Elong.
Fisher's N.S. Index ...	=0·38	Tons/sq. in.	Tons/sq. in.	% on 2 in.
Buchmann's N.S. Index	=0·25	5·2	6·2	7·0

Fig. 10. Wohler fatigue test results on solution-treated Elektron AZ.91.

Test specimens machined from D.T.D. sand cast test bars. Heat-treatment, 8 hrs. at 395° C., 16 hrs. at 420° C., 16 hrs. at 190° C. Test specimen 0·400 in. dia. Semi-circular notch 0·047 in. radius.
Endurance values given in "Technology of Magnesium" for sand cast and fully heat-treated Elektron AZ.91
Unnotched ± 5·7 tons/sq. in.
Notched ± 4·3 tons/sq. in.

Composition %.					
Al	...	9·5	Mn	... ...	0·3
Zn	...	0·4	Mg	... remainder	



Static Tensile Test Results.
Average of 3 or more tests from same material.

		0·1% P.S.	U.T.S.	Elong.
Fisher's N.S. Index ...	=0·43	Tons/sq. in.	Tons/sq. in.	% on 2 in.
Buchmann's N.S. Index	=0·30	7·3	16·3	2·5

Fig. 11. Wohler fatigue test results on fully heat-treated Elektron AZ.91.

$$\text{Sensitivity index} = \frac{\text{notch effect index} - 1}{\text{stress concentration factor} - 1} \quad (3)$$

$$\text{notch effect index} = \frac{\text{fatigue strength when unnotched}}{\text{nominal fatigue strength when notched.}}$$

Peterson's expression is similar and the terminology is as follows :—

$$\text{Sensitivity index "q"} = \frac{kf - 1}{kt - 1} \quad (4)$$

$$kf = \frac{\text{endurance limit with no stress concentration}}{\text{endurance limit for notched specimens.}}$$

NOTCH SENSITIVITY COMPARISONS.

COMPARISON BETWEEN BUCHMANN'S AND FISHER'S NOTCH SENSITIVITY INDICES.

$$\text{FISHER'S N.S.I. } (=F) = \frac{1 - \frac{1}{\text{N.E.I.}}}{1 - \frac{1}{\text{S.C.F.}}}$$

$$\text{BUCHMANN'S N.S.I. } (=B) = \frac{\text{N.E.I.} - 1}{\text{S.C.F.} - 1}$$

N.S.I. = Notch Sensitivity Index.
S.C.F. = Stress Concentration Factor.
N.E.I. = Notch Effect Index.

S.C.F.	(N.S.I. B.orF.)	N.E.I. 1·00	N.E.I. 1·25	N.E.I. 1·50	N.E.I. 1·75	N.E.I. 2·00	N.E.I. 2·50	N.E.I. 3·00	N.E.I. 4·00	N.E.I. 5·00	N.E.I. 6·00	N.E.I. 7·00	N.E.I. 8·00
8·0.. ..	B.	0	0·04	0·07	0·11	0·14	0·21	0·29	0·43	0·57	0·71	0·85	1·00
	F.	0	0·23	0·38	0·49	0·57	0·69	0·76	0·85	0·91	0·95	0·98	1·00
7·0.. ..	B.	0	0·04	0·08	0·13	0·17	0·25	0·33	0·50	0·66	0·83	1·00	1·16
	F.	0	0·23	0·39	0·50	0·58	0·70	0·78	0·88	0·93	0·97	1·00	1·02
6·0.. ..	B.	0	0·05	0·10	0·15	0·20	0·30	0·40	0·60	0·80	1·00	1·20	1·40
	F.	0	0·24	0·40	0·51	0·60	0·72	0·80	0·90	0·96	1·00	1·03	1·05
5·0.. ..	B.	0	0·06	0·13	0·19	0·25	0·38	0·50	0·75	1·00	1·25	1·50	1·75
	F.	0	0·25	0·42	0·54	0·63	0·75	0·83	0·94	1·00	1·04	1·07	1·09
4·0.. ..	B.	0	0·08	0·17	0·25	0·33	0·50	0·67	1·00	1·33	1·66	2·00	2·33
	F.	0	0·27	0·44	0·57	0·67	0·80	0·89	1·00	1·07	1·11	1·14	1·16
3·0.. ..	B.	0	0·13	0·25	0·38	0·50	0·75	1·00	1·50	2·00	2·50	3·00	3·50
	F.	0	0·30	0·50	0·64	0·75	0·90	1·00	1·13	1·20	1·25	1·28	1·31
2·0.. ..	B.	0	0·25	0·50	0·75	1·00	1·50	2·00	3·00	4·00	5·00	6·00	7·00
	F.	0	0·40	0·67	0·86	1·00	1·20	1·33	1·50	1·60	1·67	1·71	1·75
1·5.. ..	B.	0	0·50	1·00	1·50	2·00	3·00	4·00	6·00	8·00	10·00	12·00	14·00
	F.	0	0·60	1·00	1·29	1·50	1·80	2·00	2·25	2·40	2·50	2·57	2·63
1·0.. ..	B.	0	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
	F.	0	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞

APPENDIX.
NOMINAL ANALYSES OF ELEKTRON ALLOYS MENTIONED.

Alloy designation	Nominal alloy content. % by weight of:— Al	Zn	Mn	Total Impurities
A 8	8·0	0·4	0·3	< 0·3
AZ 91	9·5	0·4	0·3	< 0·3
Melelif A 5..	5·0	0·4	0·3	< 0·3
AZM	6·0	1·0	0·3	< 0·3

(Peterson names this factor the "effective stress concentration factor in fatigue." It is, of course, the same as Buchmann's "notch effect index").

$$kt = \frac{\text{maximum stress}}{\text{nominal computed stress}} = \text{stress concentration factor.}$$

Formulae (3) and (4) are obviously identical and have been arranged so that the sensitivity index values are obtained on a positive scale from zero where no reduction in strength results from stress concentration at the notch, to unity, where the full theoretical stress concentration effect is produced.

The defect in this method is that while it compares the actual material with the ideal, the comparison is not one of loss of strength but of increase in stress. Loss of strength, however, is not proportional to increase in stress, even on perfectly elastic material, as can be seen from the following figures, calculated for specimens all of the same material and of the same diameter at the bottom of the notch.

Furthermore, on non-elastic materials it is very unlikely that the material breaks always at a fixed stress level, owing to the generation of triple-tensile

TABLE I.

Condition of test specimen.	Breaking stress of material (say)	Breaking load (say)	Average Stress	Loss in Strength	Increase in stress at notch (to reach breaking stress)
Unnotched	10·00 T.S.I.	100 lbs.	10·00 T.S.I.	0	0
Notch A	10·00 T.S.I.	66⅔ „	6·67 T.S.I.	33⅓%	50%
Notch B	10·00 T.S.I.	33⅓ „	3·33 T.S.I.	66%	200%

notches of different sharpness. This makes the "increase-in-stress" basis for notch sensitivity comparisons still less applicable.

Table II shows the difference in values obtained by the two methods as represented by formulae (2) and (3), i.e., on the "loss in strength" as against the "increase-in-stress" basis. It will be seen that in some cases the order of sensitivity is reversed by the use of the alternative formula. For example, comparing two specimens say "X" and "Y"; where "X" shows a loss of strength of 50 per cent. with a notch effect index of 2·0 and a stress concentration factor of 8·0, Buchmann's formula gives the sensitivity as 0·14 or 14%, Fisher's formula as 0·57 or 57%. "Y," however, shows a loss of strength of 20% with a notch effect index of 1·25 and a stress concentration factor of 2·0, and Buchmann's formula gives it a sensitivity of 0·25 or 25%, against Fisher's 0·40 or 40%.

Thus, by Buchmann's formula, "Y" is about 100% more sensitive than "X," but by Fisher's "X" is about 30% more sensitive than "Y." This example shows the desirability of early agreement on the method of assessing and expressing notch sensitivity.

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2 "Zinc Die Casting Alloys." Morgan and Darrah. *Metal Industry*, Dec. 3, 1943.
3 "Properties of Zinc Alloy Die-castings." A. Street. *Engineering*, Dec. 29, 1944.
4 "Tests on Notched Bars of Different Sizes." Philpot, *Brit. Assn.* Sect. G., 1924.
5 "Characteristics of Notched Bar Impact Tests." Stanton and Batson. *Proc. I. C. E.*, 1920–21. Part I.
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8 "Tensile Impact Tests." H. C. Mann, A.S.T.M., 1936.
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16 "Stresses in a Plate." Inglis. *Trans. I.B.N.A.*, 1913.
17 "Stress Concentrations." Timoshenko, Inter. Cong. App. Mech., 1926.
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26 "Stress Concentration Phenomena." Peterson, A.S.M.E., 1932.
27 "Stress Concentration at Holes and Notches." Wahl and Beeukes, A.S.M.E., 1934.
28 "Stress Concentration at Holes and Notches." Timoshenko and Dietz, A.S.M.E., 1925.
29 "Dauerfestgkeit und Kunstruktion." Thum and Buckmann, 1932.
30 "Fatigue Properties of Cast Iron." Kommers, A.S.T.M., 1929.
31 "Effect of Temperature in Impact Test." Greaves and Jones, *J.I.M.* (II)
32 "Shock Tests and Their Standardisation." Hadfield and Main. *Proc. I. C. E.*, 1920–21.
33 "Technical Cohesive Strength." W. Kuntze, 1932, *J.I.S.I.* (translation), 1941.
34 "Technical Cohesive Strength." McAdam, A.S.M.E., 1941.
35 "Technical Cohesive Strength." McAdam, *Mech. Tech.* Jan., 1942.
36 "Technical Cohesive Strength. McAdam and Mebs, *Metals Tech.*, August, 1943.
37 "High Speed Testing." Lean and Quinney. *Proc. I. Mech. E.*, 1937.
38 "Velocity Effect in Notch Brittleness." Docherty, Brit. Assoc., G.1928. *Engineering*, Nov. 9, 1928.
39 "Effect of Bending Rate on Notch Impact Values." Docherty, *Engineering*. Mar. 13 and 17, 1931.

SCIENTISTS in all branches will, doubtless, have noted with satisfaction the recent announcement of an increased allocation of paper to book publishers. Since the end of the war, the position regarding scientific textbooks has apparently worsened rather than improved. This appearance may be only illusory, but it is probable that it has some foundation in fact, since the demand must be increasing rapidly. In any event, no book of importance seems to remain available for any appreciable length of time, and the number of scientists and students who hopefully lodge their names with booksellers "awaiting supplies" is legion. An improvement in the situation is doubly necessary, since it is to be feared that the supply of scientific works from the United States, already a mere trickle, may, because of the dollar situation, dry up completely. No remedy that we can see will act as a short-term cure. It is necessary, then, at least to develop a long-term policy. Scientists (and scientists in the making) need books—British books which have long been out of print or in short supply; books to replace the valuable American texts which, as far as this country is concerned, might almost be out of print; and, finally, new books. An increased paper ration to publishers, if rightly used, seems to offer us some promise of relief in each of these groups. We can only pray that it will not, instead, merely result in an inflated issue of bookstall bloods.

Methods of Micro-Filtration for Quantitative Analysis

By F. Burton

The process of filtration, one of the commonest operations in chemistry, has offered a wide scope for the ingenuity of the microchemist. A selection of the varied ways in which filtration may be carried out on a small scale is described in the following article.

FILTRATION is probably the most important operation in both macro and micro analysis, whether qualitative or quantitative, and as such is the most frequent source of error. Efficient filtration is of even greater importance in quantitative micro analysis since any contamination or loss in the transference of precipitates gives rise to a high relative error. Obviously filtration by the filter paper method, which finds wide application in macro-analysis, cannot be applied to the micro scale since the small amounts of liquid involved would be completely absorbed by the paper. This difficulty has been overcome, for many efficient micro-filtration methods have been devised. A number of these is described below. It is of interest to note that although many of the types described may be bought commercially, the majority can be made quite readily by anyone possessing average glass-working abilities.

A small hand centrifuge is the most convenient method for the rapid separation of liquids and solids. Although centrifugal methods of filtration are more usually employed in qualitative analysis, they have been used in the quantitative estimation of sodium, phosphorus and the like. The usual type of centrifuge is provided with two heads carrying metal shells into which are placed the small centrifuge cones containing the liquid to be separated. Centrifuging causes the precipitate to collect in the point of the cone leaving the clear supernatant liquid which may be removed by means of a capillary pipette (Fig. 1). The tip of the pipette is gradually inserted into the liquid until it is immediately above the precipitate; if both centrifuge cone and pipette are sufficiently inclined to the horizontal, the liquid rises in the pipette by capillary attraction. When comparatively large volumes of liquid are to be removed, it is more convenient to carry out the separation of precipitate and solution by means of a capillary siphon (Fig. 2). A piece of capillary tubing is bent to the shape shown. The short arm is inserted into the solution and the long arm placed in an empty centrifuge cone which serves as a collecting vessel.

Capillary filtration (Fig. 3) is a simple but effective method widely used in qualitative analysis when separation quite often has to be carried out on a microscope slide. A fine capillary is further drawn out to a hair tip which is placed in the drop to be filtered.

Capillary attraction is usually strong enough to draw the liquid into the tube leaving the precipitate intact on the slide for further treatment. When dealing with very fine precipitates it is advisable to widen the tip of a capillary pipette and wedge a small roll of filter paper or a tuft of asbestos in the constriction formed. The solution is removed by mouth suction and the filter carefully removed and returned to the main precipitate.

A modification of capillary filtration[1] is shown in Fig 4. The test liquid and precipitant are introduced into a capillary tube with a sealed end and are thoroughly mixed with a glass thread. A tuft of asbestos is placed above the solution, (Fig. 4B) and the capillary is slightly drawn to form a constriction above the asbestos (Fig. 4C).

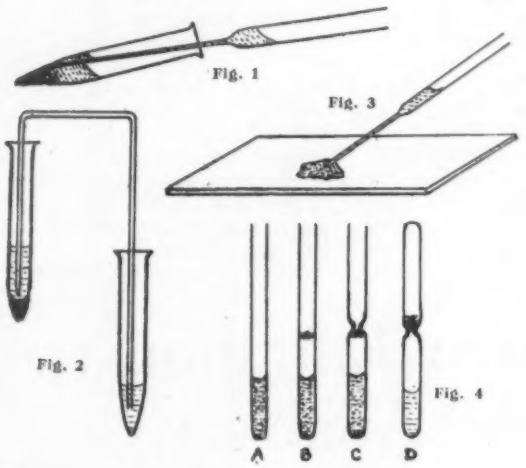

Fig. 1.—Filtration in a centrifuge cone.
Fig. 2.—Transference by siphoning.
Fig. 3.—Capillary filtration.
Fig. 4.—Filtration in a sealed capillary.

After sealing the upper end of the tube, separation may be effected by inverting and centrifuging (Fig. 4D). This method finds its greatest application in recrystallisation, but nevertheless can be used for straightforward filtration.

Caley's filter pipette[2] (Fig. 5) for use in qualitative analysis, consists of a T-tube, the short arm of which is closed by a rubber teat. The upper end of the body of the pipette terminates in a piece of narrow vacuum tubing while the lower end is slightly elongated. A small piece of filter paper is placed in the position shown. In use, the rubber teat is depressed and the lower end closed while the liquid is poured drop by drop onto the filter paper. When the pressure on the teat is released the solution filters into the T-tube.

Another convenient filtration procedure, though only of qualitative value was introduced by Hemmes[3] (Fig. 6). A small rectangular piece of thick filter paper is placed beside the drop awaiting filtration. The evenly ground end of a small pipette is lightly pressed on the paper and mouth suction applied. As in capillary filtration, no suction is necessary when very small amounts are to be removed, since the liquid rises by capillary action alone.

The first micro-quantitative determinations involving filtration were carried out by Emich and Donau.[4] The simple form of apparatus used is shown in Fig. 7. It consists of a glass tube (ground flat on top) drawn out to form a "filter capillary." A small disc of filter paper having a turned-up greased edge is placed on top of the funnel. Mild suction is applied, and the liquid to be filtered is poured dropwise on to the paper; the filtrate may be collected if required. The precipitate is retained by the filter paper, which after washing is folded in a piece of weighed platinum foil, ignited and reweighed.

A micro-suction filter devised by Schwinger[5] (Fig. 8) consists of a thick walled glass tube of 2–2·5 mm. bore, the upper end of which is ground flat and polished, while the lower end is cut off obliquely. The upper part of another tube having the same outside diameter but a slightly larger bore, is widened to form a cylinder. The lower end of this tube is ground and polished enabling it to fit exactly to the first tube. A micro-filter in the form of a disc of filter paper is placed between the ground surfaces and the two tubes are then joined by a piece of rubber tubing. The filter is mounted in a suction vessel connected to a pump.

The Willstätter "Nail"[6] (Fig. 9) is a simple filtering devise which facilitates removal of the precipitate. The glass "nail" fits into the cone of a small glass funnel, the head thus providing a support for an asbestos mat or filter paper disc. The apparatus is connected to a filter flask and the usual method can be used for applying suction.

Donau dishes[7] provide a clean and convenient method of separation. They are in fact micro-Gooch crucibles which may be readily made from platinum foil of about

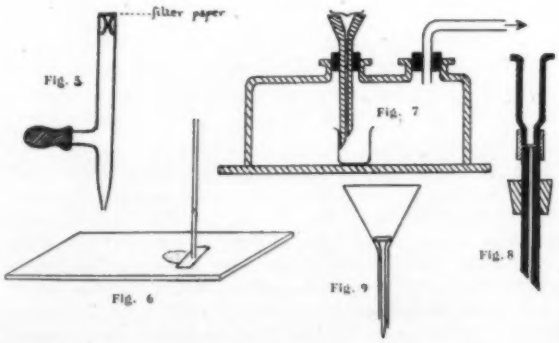

Fig. 5.—Caley's method of filtration.
Fig. 6.—Filtration by Hemmes's method.
Fig. 7.—Filtration by the method of Emich and Donau.
Fig. 8.—The Schqinger micro-suction filter.
Fig. 9.—The Willstatter "Nail."

0·004 mm. thickness using a simple stamping out process. Satisfactory dishes have been made using a glass rod as a stamping die and a rubber bung for the base.

1 Emich, *Microchemical Laboratory Manual*, p. 31, New York, John Wiley & Sons, 1932.
2. Feigl, "Spot Tests," p. 9, 2nd edn. 1939.
3 Emich, *Microchemical Laboratory Manual*, p. 25.
4 Emich and Donau, *Monatsh.*, 1909, **30**, 754.
5 Emich, *Microchemical Laboratory Manual*, p. 30.
6 Willstätter, *Chimie and Industrie*, 1936, **36**, 311.
7 Emich, *Microchemical Laboratory Manual*, p. 75.

The base of the crucible is perforated with fine holes and a layer of asbestos inserted as the filtering medium.

Strzyzowski filter funnels[8] (Fig. 10A) are available commercially in various sizes. The funnels are constricted at the point X above which is a thin layer of purified asbestos. Filtration may be brought about either by suction or by centrifuging. If the latter is chosen, the funnel is placed in a large centrifuge cone, filled with the liquid to be filtered, centrifuged slowly at first and then with increasing speed.

These funnels may easily and quickly be made by allowing the walls of a capillary tube drawn out to the shape shown in Fig. 10B to collapse in the small flame of a microburner. A layer of asbestos is placed above the constriction and filtration carried out as described. In dealing with very small amounts of solution, the tip of the capillary may be sealed so that the funnel retains both precipitate and filtrate.

When a large number of transferences has to be made it is advantageous to use a series of filter beakers of the type described by Schwarz-Bergkampf[9] (Fig. 11). They have the advantage of combining filter and beaker so that precipitation and filtration can be carried out in the same vessel. Their method of use in series will be apparent from the illustration.

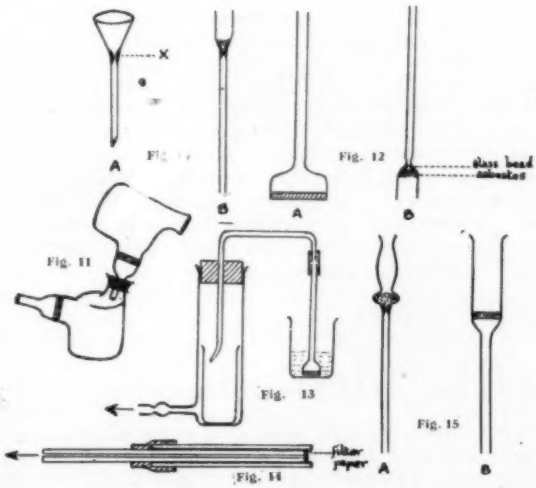

Fig. 10.—The Strzyzowski filter funnel.
Fig. 11.—The Schwarz-Bergkampf filter beaker.
Fig. 12.—Emich filtersticks.
Fig. 13.—Emich method of filtration.
Fig. 14.—The King filterstick.
Fig. 15.—Pregl filter tubes.

The Emich filter-stick or micro-suction filter[10] is one of the more popular methods of filtration. General types of filter-stick are shown in Fig. 12 ; the method of filtration in Fig. 13. The apparatus consisting of micro-beaker and filter-stick is usually of Jena glass, but if the precipitate has to be ignited the micro-beaker is replaced by a small porcelain crucible and the glass filter-stick by one of porcelain, quartz or platinum. Each filter-stick is used in conjunction with its own beaker or crucible, the two being weighed together at the start of a determination. The sample to be analysed is weighed into the vessel, solution and precipitation are carried out and the precipitate filtered using slight suction with the aid of a pump. Drying and ignition is followed by a weighing of the precipitate, beaker and filter-stick.

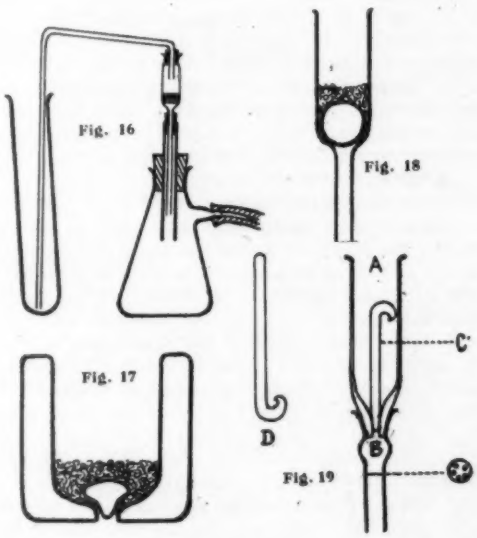

Fig. 16.—Pregl's method of filtration.
Fig. 17.—The Bailey filter crucible.
Fig. 18.—The Dunbar micro Gooch filter.
Fig. 19.—The Kirk-Craig filtration apparatus.

Fig. 12B shows an easily made filter-stick in which the filtering layer is of asbestos. Jena glass combustion tubing is drawn out to the required shape and a constriction formed at the head of the stem. A small coil of platinum wire or a glass bead is placed at the constriction to act as a base for the asbestos and prevent choking of the capillary. An asbestos layer of required thickness is then inserted. Filtration is effected as described above.

An alternative form of filter-stick is due to King[11] (Fig. 14). It is used in the same manner as the Emich filter-stick and can be readily fashioned from a piece of thick walled capillary tubing which fits snugly inside a piece of laboratory glass tubing. The ends are ground and polished ; the two tubes are held firmly in position by a rubber sleeve. A disc of filter paper placed as shown serves as the filter, filtration being carried out under suction. Using the inner tube as a piston, the filter together with any precipitate can be extruded and returned to the bulk of the precipitate.

A development of the King filter-stick is similar in shape to the type used by Emich. A sintered glass base presents a larger filtering surface and also acts as a foundation for the filter paper which is accommodated in the bell-shaped end of the outer tube.

8 *Ibid.*, p. 29.
9 Schwarz-Bergkampf, *Z Anal. Chem.*, 1926, **69**, 321.
10 Emich, *Microchemical Laboratory Manual*, p. 68.
11 King, *Analyst*, 1933, p. 325.

Filter tubes of the type originated by Pregl[12] have a filtering surface of either asbestos (Fig. 15A) or sintered glass which is usually covered with a thin layer of asbestos (Fig. 15B). Precipitation is carried out in a separate vessel and the precipitate transferred by suction to the filter in the manner shown in Fig. 16.

The simple yet efficient filter crucible shown in Fig. 17 was designed by Bailey.[13] The end of a Pyrex glass tube of outer diameter 10 mm. is heated strongly until partially closed. The base of the crucible is formed by pressing the still plastic end of the tube on an asbestos mat. Droplets of Pyrex glass are made to fit to the interior aperture of the crucible and so form a base for the asbestos pad used as filter. It is important that the asbestos filter is not disturbed when the crucible is set down ; therefore the tip of the drop must not protrude below the bottom of the crucible. In actual filtration, the crucible is connected to the suction apparatus by a piece of stout rubber tubing.

The Dunbar micro-Gooch filter[14] (Fig. 18) can be readily constructed by drawing out a piece of wide glass tubing to the shape shown. The ends are ground and polished ; a solid round glass bead is used as a support for the asbestos filter mat. Its method of use is exactly as with the conventional type of Gooch crucible.

Kirk and Craig[15] describe an apparatus combining filter and precipitation vessel which eliminates the necessity of transference of precipitate. The assembly of the apparatus is shown in Fig. 19. The reaction vessel A is made from a portion of a test tube which is fused at the lower end to a piece of heavier tubing suitable for grinding. A hooked solid glass rod C is ground into the tapered end of A which is in turn ground into the top of the filter tube B. A filter disc of perforated platinum foil is inserted into the filter tube and fused into position about 1 cm. below the ground joint. The second glass rod D having a hooked end, is required for the removal of rod C from its position after precipitation has been performed.

12 Pregl-Fyleman, "Quantitative Organic Microanalysis," 2nd edn., London, 1930.
13 Bailey, *Ind. Eng Chem.*, Anal. Ed., 1937, **9**, 490.
14 Dunbar, *Ibid.*, p.

The following procedure is adopted. A thin layer of fine asbestos is placed on the filter disc and the filter tube is weighed prior to connection to a suction flask. Precipitation is carried out in A with C in position, and when completed the ground end is inserted into the head of B. With the aid of D, rod C is removed from its seat and after washing is hung over the edge of A. Slight suction is applied at the time of removal of C. The precipitate is washed in the usual way and when all adherent particles have been removed from the walls of the reaction vessel, it is disconnected from the filter tube. The latter is washed further, is dried and finally reweighed.

Methods of filtration in semi-micro-analysis have been advanced by Barber.[16] A suitable filter is placed in the constricted lower end of a centrifuge cone having a small orifice, which is suspended in a test tube. The solution is filtered under pressure supplied by depression of a rubber ear syringe. Alternatively the precipitate may be collected in a modified Strzyzowski funnel which is inserted in a filter tube with side arm. Here the solution is filtered by suction. The bulb of the syringe is depressed and the narrow end inserted in the side arm of the filter tube which may be set aside for the time of filtration, enabling the analyst to continue with other work.

To conclude this survey, reference must be made to a useful filter pipette which was recently described in this journal by Wilson.[17] It consists of a piece of thick walled capillary glass tubing whose tapered end is fitted with a tuft of asbestos or cotton wool. A rubber teat closes the upper end of the pipette ; the speed of filtration is governed by control of the pressure on the teat. It is possible to construct interchangeable filter tips which may carry filters either of asbestos or sintered glass. They are drawn to fit to the tapered end of the pipette and a ground connection made with a paste of carborundum and water. For a full account of the construction and manipulation of the pipette, the reader should consult the original paper.

15 Kirk and Craig., *Ibid.*, 1931, **3**, 345.
16 Barber, *Ibid.*, 1940, **12**, 58. (cf also Miller, METALLURGIA, 1944, **31**, 39).
17 Wilson, METALLURGIA, 1945, **31**, 320.

Recent Photometric Methods

THE spectrophotometer has been applied to the determination of small amounts of calcium.[1] The principle of three varying methods which are described is to precipitate the calcium as oxalate, and allow the precipitated oxalate to react with potassium permanganate, subsequently measuring the transmittance of the permanganate solution. Several wavelengths have been investigated for suitability, and it was found that Beer's Law holds precisely over the range of 0·2 to 2·0 mg. of manganese per 100 ml., at 529mμ. Comparison of the estimation with other methods, and examination of the effect of other substances suggest not only that the method is equivalent in accuracy to other standard methods, but that in addition it might well be applied to the determination of other materials oxidised by permanganate, following the same principle that is outlined here.

The photometric estimation of lead in steels has been described by Bricker and Proctor.[2] A preliminary extraction of the lead is carried out under controlled conditions, with ammonium hydroxide and sulphuretted hydrogen. The lead is then extracted at pH 9·0—9·6 with a dithizone solution in chloroform, using successive portions till the colour indicates that no more lead is being extracted. The total colour may then be estimated by comparison with standards, or photometrically, using the wavelength 520 mμ.

1 R. E. Scott and C. R. Johnson, *Ind. Eng. Chem. Anal. Ed.*, 1945, **17**, 504.
2 L. G. Bricker and K. L. Procter, *ibid*, 511.

A COPY of the book entitled "Semi-Micro Quantitative Organic Analysis" has been received. The authors are R. Belcher and A. L. Godbert and it is published by Longmans, Green and Co., London. It is demy 8vo in size, 168 pp with 42 figures. Price 10/6 net.

ERRATA.

The Note by R. Belcher and S. M. Randall, dealing with Extraction Apparatus, which appeared in our last issue, contained two errors. On page 240, line 7, 0·4mm. should read 0·4 cm. Similarly, in line 10, 0·2 mm. should read 0·2 cm.

Galvanising

By W. H. Spowers

THE process of galvanising, as carried out at the Navy Yard, Portsmouth, N.H., U.S.A., is described. After summarising some of the principles of zinc coating, consideration is given to pickling, washing, fluxing and galvanising, with special reference to alloy layers on bonding and the formation of zinc dross. Special reference is also made to centrifugal galvanising used for various small articles such as threaded nuts and bolts and also for assemblies of single, double and treble blocks of various sizes from 4 in. to 24 in., all of which contain snatch block fittings, swivel hooks and swivel fork shackles, one to five in number, requiring to turn freely after galvanising.

An investigation is also described, conducted for the purpose of determining the effect of the concentration of sulphuric acid on the time of pickling. Sheets of 20 gauge standard enamelling steel, 4 in. by 6 in., were annealed at 750° C. for two minutes in an electric furnace. Three samples of each were then pickled in sulphuric acid of the following concentrations: 1 to 15% inclusive, 20%, 25%, 30%, 40% and 50%, at temperatures of 77°, 105°, 120°, 150° and 180° F. respectively. The average results obtained are given in Table I, the times required for complete removal of the oxide by the action of the acid being recorded.

At 77° F. the acid concentrations requiring the least time for pickling are between 20 to 40%, and these concentrations pickle in 13 minutes or lower with 8 minutes for the 25% solution. A rapid rise in pickling time is found with the 50% acid. Somewhat similar results are obtained at 105° F, except that the acid concentrations requiring the least time are those between 12 and 40%. At 120° F., the best concentration appears to be between 8 and 30%, the time of pickling being 5 minutes or lower. The best practical concentration is about 5%, which requires 4 minutes time for pickling. The most rapid acting concentrations at 150° F. are from 4 to 40% inclusive, all of which pickle in 3½ minutes or less, and at 180° F. the time for pickling at all concentrations is 2½ minutes or lower, except in the 50% concentration. At 30% and higher concentrations, a black scum was left on the sheets both at 150° and at 180° F.

TABLE I.—RESULTS OF PICKLING TESTS.

Strength of Sulphuric Acid % by Weight	Time required to Pickle at Temperatures				
	77° F.	105° F.	120° F.	150° F.	180° F.
	Min.	Min.	Min.-sec.	Min.-sec.	Min.-sec.
1	80	24	14	8	2–30
2	45	15	8	4–30	1–30
3	40	15	5	4	1–30
4	35	14	6	3*	1–15
5	30	13	4	3–30	1–15
6	28	12	5	3	1–15
7	25	11	4	3	1–15
8	22	12	4	2–30	1–15
9	20	12	4	2–30	1–15
10	20	11	5	2–30	1–10
11	20	11	5	2	1
12	20	9	5	2	1
13	18	8	5	2	0–55
14	16	8	4	2	0–45
15	15	8	4	1–30	0–45
20	9	7	5	1–30	0–30
25	8	6	4	1–30	0–25
30	12	7	4	1–30	0–20
40	13	6	5–30	2	1
50	30	18	17	25	8

The time required for pickling at all concentrations of 40% or lower is rapidly diminished with increase in temperature, especially up to 120° F. The time of pickling is also accelerated much more by rise in temperature than by increase in acid concentration. The increased time of pickling above 40% acid strength is due to the decreased ionisation and probably partially due also to the oxidising effect of the hot concentrated sulphuric acid, both of which retard the solution of iron and the formation of hydrogen gas which forces the scale of the plate. The best temperature for the most rapid and practical pickling appears to be between 120° to 150° F., and the most practical and economic concentrations at those temperatures appears to be 5% sulphuric acid.

The loss in weight of sheets in the acid was also determined and showed that pickling time increased more with the per cent. of steel dissolved than it did with increase of acid concentration. Sheets at 77° F. lost 3·2% by weight with 1% acid requiring 80 minutes; at 6% acid concentration and 28 minutes time, the loss was 2·5%; and at 10% concentration and 20 minutes time, the loss in weight was 2·1%. A piece of steel which had been annealed four times required 10% more time to pickle at room temperature after the fourth annealing than it did to pickle the same after the first annealing.

From *Journal of American Society of Naval Engineers*, 1945, Vol. 57, No. 1, pp. 78–90.

Magnetic Powder Inspection and its Practical Application

By J. W. Jenkins and K. D. Williams

MAGNETIC powder inspection is a non-destructive method of detecting surface metallic discontinuities in ferrous materials in which the procedure consists of magnetising the part under inspection and then flowing a wet suspension of paramagnetic particles, or dusting, or lightly blowing mobile dry paramagnetic particles on to the surface. Magnetic discontinuities tend to form leakage flux fields or flux disturbances into which the particles align themselves and thereby outline or indicate the defect. Magnetising is accomplished by using direct current, rectified alternating current or alternating current. Current may be applied directly to the part to be magnetised or passed through coils placed longitudinally around the part or at 90° or other angle to its axis for purposes of indicating defects expected to exist in various positions, and the powder may be applied while the magnetising current is flowing or residual magnetism may be sufficient. Cracks, inclusions, sandsplits, folds, laps, etc., are all indicated in a similar manner, depending upon the conditions present. Overmagnetising, sharp section changes, stress gradients, localised flux concentrations and other reasons may also cause paramagnetic particle patterns to form.

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Magnetic powder inspection has been found to be particularly useful in the field of welding, to indicate defects which are sub-surface and for the examination of forgings. In applying such inspection to welding it can only be used as a pointer to indicate that some defect exists. The qualitative as well as the quantitative aspects of the defect have to be determined by grinding, followed by rewelding when the defect is removed. In the examination of forgings for flakes (thermal cracks), seams and laps, slag inclusions and sand splits, other non-metallic inclusions and pipes or bursts, magnetic testing can be used for acceptance purposes, in which case it is necessary to form a recommended procedure.

Forgings should be inspected at intervals during the machining operations, if practicable. After the magnetic powder has been applied, the forging should be examined from end to end. All fillets and parts having the smallest diameter should be examined carefully. Any tendency for the powder to pile up at a defect may indicate greater depth of the discontinuity. When defects are indicated, the powder should be brushed away and the areas in which they occur examined with a 10 power hand magnifier and a portable light, in order to observe whether the defects contain slag and whether the defects are narrower at the ends which indicates inclusions. Such inclusions are often comparatively shallow and can be removed by a small file. The ends of forgings should be examined for thermal cracks which are strongly defined by the magnetic powder. On the size, distribution and location of inclusions in transverse surfaces depend the usability of a forging, particularly if such inclusions are in regions of high stress.

The setting up of standard limitations for sizes and frequency of occurrence of inclusions in forgings must be tempered by specific design requirements. Such limitations have been applied to the acceptance of inclusions in the main body of forgings designed with a high factor of safety. In shaft surfaces other than journal areas, inclusions 1 in. long and not more than 0·035 in. deep have been considered acceptable, but it has ordinarily been necessary to explore most of the inclusions over 1 in. by hand filing or grinding in order to be assured that they are not over 0·035 in. deep. In the surface of journals, inclusions not over 0·010 in. deep, have been considered acceptable, when not more than one inclusion over 1 in. long occurs in any one journal area, and where all inclusions cleaned up by filing or grinding so that no particle, either non-metallic or metallic became detached in service. Gear and pinion forgings should be free from inclusions on gear tooth contacting surfaces.

A useful method of establishing a permanent record of magnetic powder indications has been devised. This method consists of transferring the indications upon either surgical adhesive tape or scotch tape. In each case the object bearing the indications is wrapped with the tape and when the tape is removed it carries the magnetic powder indications. If surgical tape is used, cellophane should be applied to the adhesive surface, but if scotch tape is used, plain paper may be applied.

An investigation carried out by the General Electric Company on the magnetic powder inspection of three turbine rotor forgings of various sizes for thermal cracks located at various diameters, using different mediums and conditions of applied magnetism, has led to certain general conclusions. Circular magnetisation is the more effective method for the magnetic particle testing of such forgings and circular magnetism with direct current obtained from generators, copper oxide rectifiers or storage batteries gives equivalent results. D.C. is more effective and A.C. and the D.C. continuous method is the most sensitive and most definite for revealing surface defects. The D.C. residual method is slightly less effective than the D.C. continuous method. The D.C. surge method is between the D.C. continuous and D.C. residual methods in effectiveness, and the bipolar method (electromagnets) may be used, but it is not as effective or efficient as circular magnetisation. G.E. magnetic and Magnaflux paste give equivalent results and the wet method of testing is more sensitive than the dry method.

Continuous Casting

AT a joint session of the Iron and Steel Division and the Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers in 1944, a symposium was held on continuous casting. The symposium was introduced by C. E. Swartz and papers were read and discussed dealing with the continuous castings of metals from a historical, metallurgical, and economic point of view, with improvements in the direct casting of strip metals, with the Soro process and with the Williams process of casting metals.

T. W. Lippert, dealing with continuous casting in the past and at present, stated that over several years the brass, copper, magnesium and aluminium industries, so far as the United States was concerned, have shifted practically completely from conventional static moulds to continuous casting machines, and that the product as continuously cast was superior metallurgically, less scrap loss was involved, costs were generally lower, and the equipment required little floor space. The history of the continuous process from the time of Bessamer to 1940 was dealt with briefly. In the latter year a definite period of continuous casting activity came into vogue. In the strip - sheet field Hazalett had a number of wide casting-rolling mills in experimental operation and Merle was doing some work with high-speed film casting of strip. The continuous casting of rods and ingots was showing great promise. A number of Alcoa direct casting machines were in operation, Poland and Eldred were successfully producing quality copper rod, Williams was experimentally casting steel billets and Junghans had one billet-casting machine in operation on brass. To-day the picture had again shifted and expanded. Work on continuous cast sheet or strip had faltered or died and many of the machines were scrapped, but as regards continuously cast ingots and bars, the technology had expanded. A brief outline of interim changes and current status of the above-mentioned continuous casting processes was given, together with those of the Goss, U.S. Steel Corporation, Hopkins, Dow, Reynolds Metals, Inco and Soro processes.

The continuous casting of molten metals was also dealt with by N. P. Goss. Historical developments were dealt with for over 70 years and the experimental work carried out and the many patents taken out with regard to the process were briefly described. The requirements for continuous casting were considered and it was stated that the success of the process depended largely on the mould and the manner in which the metal was teemed or extracted from the mould. A mould must have a good thermal conductivity, it must resist distortion, it must resist disintegration when subjected to the intense heat of the casting moving

From *Metals Technology*, 1945, Vol. 12, No. 2, and A.I.M.M.E. Technical Paper No. 1793, pp. 1–46.

through the mould, the chill surface must be non-wetting and smooth to facilitate movement of the casting through the mould, and the mould must not rupture when water-cooled, and so far only two materials have met these requirements—copper and graphite. Metal must also be teemed into the mould with a minimum of turbulence. The author also described in detail a process (the Goss process) in which experiments had been made to overcome sticking in the mould, distortion in the mould and fracture of the casting as it passed through the mould. The mechanism of solidification, and the metallurgical and economic aspects of continuous casting were also dealt with.

Improvements in the direct rolling of strip from molten metal was dealt with by C. W. Hazlett, who gave a résumé of some of the accomplishments which had taken place in this branch of continuous casting. Some experimental developments in recent years in connection with the rolling of brass and aluminium strip, such as the problem of the cooling surface and its renewal and cost and also the important problem of better edge compensation in a mill using bath distribution of the metal were also dealt with. Reference was made to the development of a mill for low-melting point metals which produced very thick or very thin gauges with pressures and horse-powers of 1% less than those previously used and which had dealt to a very large extent with the problems referred to.

The Soro process of continuous casting, applicable to ferrous and non-ferrous alloys, and capable of producing rod from ½ in. to approximately 4 in. in diameter or other simple solid shapes of a corresponding cross-sectional area was dealt with by E. I. Valvi. The equipment required was described and the technique required for the process summarised. Casting and straightening are the critical operations. In casting, the amount of chill must be adjusted to the cross-section of the casting, and in order to obtain the required density, uniformity of structure and smoothness of surface, the speed of rotation and the rate of pouring must be controlled. In the straightening operation, the speed of pull must match the rate and amount of precompressing for any given alloy and cross-section. Precompressing is necessary in order to permit the use of high speeds, such as are customary in conventional drawing operations, and in preventing the occurrence of hair-line cracks and other more serious defects in straightening. Consideration was also given to the properties of the product of the Soro process and its application. It was also considered that the process would make good use of secondary metal and scrap.

In dealing with the Williams continuous casting process, E. R. Williams stated that continuous casting of carbon and alloy steel had not yet gone into commercial production but that considerable progress was being made. In investigations on the process, which was based on the fundamental idea of fast heat removal and dissipation, research activities had been devoted chiefly to the idea of moving the solidifying ingot along a stationary mould wall. One of the principal features of the process made it possible to cast metals, particularly steel, at high lineal speeds by the use of a relatively shallow cooling passage surrounding the mould wall. Another desirable feature was the use of lubricating materials continuously applied between the mould wall and the forming ingot. In general, the process was adaptable, not only to the continuous casting of ingots, but also to the casting of single-length or stationary ingots in water-cooled moulds of similar design. After several years spent in the development of the method, ingots of brass and steel of various grades and ingot sizes have been cast successfully. Higher ingot yields, metallurgical control of ingot cooling, fast turnover of mould equipment and other outstanding advantages have also been reported.

High Quality Magnesium Castings

By A. V. Lorch

THE production of high quality magnesium sand castings free from undesirable contaminations and possessing good physical properties depends on control of certain factors in melting and pouring. As a result of careful investigations, it has become apparent what foundry variables must be controlled, and the procedures necessary when melting and pouring magnesium sand casting alloys have been determined. Such control is helped by the fact that chemical specifications for magnesium base alloys are easier to maintain within limits than any other type of foundry sand casting alloys, providing careful melting practice is enforced. Some precautions must also be taken to prevent contamination by other metals which may be present in the foundry, and also to prevent loss of alloying elements owing to segregation while melting. Silicon, lead, nickel and aluminium are likely to be contaminating elements, while decreased manganese content is possible resulting from poor melting practice.

Silicon contamination is likely to occur in the most widely used aluminium-zinc sand casting alloys whose specifications are given in Table I. The contamination is caused by chemical reduction of silica sand by molten magnesium and the presence of excessive silicon is indicated by a bluish tint on the surface of the castings and by a mottled bluish appearance of any fractured section. As such contamination is wholly the result of poor melting technique, an investigation was made to establish a correct melting procedure. Tests were first conducted to determine the temperature at which silica sand was chemically reduced and combined with magnesium. As the result of such tests it was found that the silicon content increased sharply from 0·05 to 0·18% at temperatures between 870° to 900° C. and was retained as the metal cooled to lower temperatures.

Tests were also carried out to determine the effect of fluxing as a means of separating sand from the metal by melting selected sprues and risers, with adhering sand, together with a flux. The magnesium from the scrap remelt was then subjected to six different melting procedures when silicon contents varying from 0·03 to 0·12% were obtained. The low values were obtained with thorough fluxing, low remelt temperatures and sufficient time for settling of flux and sand after stirring, while the high values resulted from agitation of the molten metal without a waiting or settling period.

As a result of the various tests, it was considered that scrap remelt pots melting metal to which particles of sand are adhering should be completely emptied after every heat of metal, in order to remove sand which has settled to the bottom of the pots during the melting operation, and that a suitable flux should be used in melting down each heat of scrap. After stirring the flux through the melt at 675° to 730° C. for several minutes, a ten minute

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settling period for the metal and flux should be allowed before any metal is ladled or poured from the remelt pots to the superheating crucibles, and metal should be transferred from the remelt pots to the superheating crucible at temperatures between 700° and 760° C. The content of the remelt pots should not exceed 760° C. in temperature, and an adequate " heel " of metal should be left in the bottom of the pot to minimise any possibility of sand being transferred with metal to the superheating crucibles. Extremely contaminated scrap should not be used, and the presence of sand in any melting pot or crucible should be avoided as far as possible.

Foundries melting and pouring both aluminium and magnesium alloys are confronted with the problem of preventing contamination due to mixed scrap. To prevent such contamination a recommended practice is to colour all gates, risers, sprues and runners with a paint crayon to identify the alloys. Miscellaneous, non-marked material should be melted, pigged and analysed before use in order to detect the presence of any contaminating elements.

Copper alloys very readily with molten magnesium, but the presence of copper lowers the corrosion resistance of magnesium alloys to such an extent that the maximum amount allowable is 0·05%. Contamination of magnesium by copper can be caused by remelting magnesium scrap having bronze chills adhering to the metal, or remelting scrap castings having bronze inserts. In the former case bronze chills can be eliminated by using iron chills and in the castings should be melted, pigged and analysed to determine if they are satisfactory for use.

Lead and nickel alloy readily with magnesium but the amounts allowable are 0·05% and 0·01% respectively. To prevent nickel contamination it is necessary to prevent alloys containing nickel from coming in contact with magnesium. Melting pots, thermocouples and skimmers should be a non-nickel containing ferrous alloy. High nickel alloy thermocouples are quickly attacked by molten nickel. The presence of nickel in magnesium alloys reduces their corrosion resistance.

Manganese is alloyed in minor quantities with the common magnesium sand casting alloys in order to enhance their corrosion resisting properties. If large tilting type holding furnaces are used for continuous melting operations, the temperature

TABLE I.—CHEMICAL AND PHYSICAL PROPERTIES OF SAND CAST MAGNESIUM ALLOYS.

Composition	A.S.T.M. B80–41T. Alloy 17		A.S.T.M. B80–40T. Alloy 4	
Aluminium ..	8·30–9·70		5·30–6·70	
Zinc	1·70–2·30		2·50–3·50	
Silicon	0·30 max.		0·30 max.	
Manganese ..	0·10 min.		0·15 min.	
Copper	0·05 max.		0·05 max.	
Nickel	0·01 max.		0·01 max.	
Magnesium ..	Balance		Balance	
Property	Heat Treated	Heat Treated & Aged	Heat Treated	Heat Treated & Aged
Yield Strength Tons per sq. in.	4·5	8·0	4·5	7·1
Ultimate Stress Tons per sq. in.	13·4	15·0	14·3	15·0
Elongation %	6·0	1·0	7·0	3·0
Brinell Hardness 500 Kg.	50	70	48–60	65

of the melt should be maintained between 700° and 730° C. in order to prevent excessive precipitation of magnesium. If such control is not exercised, manganese will be precipitated from the melt and the manganese content will be slightly below the minimum specified, Table I.

The best physical properties of magnesium sand cast alloys are obtained from fine grained metal obtained by proper superheating practice in the melting furnace, and which has been properly heat-treated.

It is recommended that the melt should be superheated to a temperature of 900° C. and held for a period of 15 minutes at that temperature. Cooling to pouring temperature should be as rapidly as possible in order to preserve the tendency to form a fine grain. When heat-treating the two alloys given in Table I, the soaking temperatures should be maintained at 405° and 395° C. respectively for 10 to 16 hours, depending on section thickness. In addition, the rate of heating during which the metal is raised to the soaking temperature should be gradual, in order to prevent incipient fusion of the intergranular aluminium-zinc-magnesium compounds in the temperature range just below the soaking temperature. A recommended preheating cycle in either case is to hold the heat for one hour at 290°C., raise in 15 minutes to 340°C., and hold for 1 hour, then raise to the soaking temperature in 15 minutes.

Strong, Light Iron Castings

By W. M. Albrecht

THE increasing demand by engineers and designers for a cast material of high strength at lower unit weight has presented a perplexing problem and a number of solutions have been attempted. For various products and in varying degrees the materials offered and used have ranged from strong cast ferrous alloys through strong cast copper alloys to the light cast aluminium alloys. Each has found its place and the areas of overlapping and competition among them is surprisingly small. For many applications where the basic requirements are high strength without excessive weight, special spheroidised iron castings, known as Z-metal, have been found suitable. In its general characteristics this material is much stronger than malleable iron and stronger than certain types of steel forgings and steel castings. Although its properties are similar in some respects to those of the so-called " pearlitic malleables," it is not exactly one of these, and it is not a heat-treated malleable iron in the usual sense at any stage of its manufacture.

The physical properties which make irons of this type interesting are obtained by close metallurgical control, inexpensive alloying and uniformity of heat-treatment. The alloying process consists of adding manganese and copper to a regular white iron base metal, and the heat-treatment consists of an annealing operation at 870° to 925° C. for about 48 hours, followed by air quenching and then by re-heating to 675° to 730° C. for 15 to 30 hours, depending on the size and section of the casting, as a toughening or spheroidising operation. The manganese alloy stabilises the structure so that reasonable manufacturing allowances in heat-treatment will permit the production of a uniform product with consistent properties. Z-Metal can be cast into any shape which malleable iron will take and as regards engineering parts can be substituted for malleable iron without changing existing pattern equipment.

The material has a high yield strength, uniformly in the order of 25 tons per sq. in., a tensile strength approximating to 37 tons per sq. in., elongation of 8 to 12% in 2 in., and a modulus of elasticity of 27,000,000 lb. per sq. in. The Brinell hardness is in the range 170 to 190 as a result of the hard spheroids of cementite which offer good wear resistance. The temper

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TABLE I.—RELATIVE CORROSION RATES.
(PARTS SUBMERGED AND NOT UNDER STRAIN—TEMPERATURE 26° C.).

Material	Salt Water 10%	Mine Water	Sugar Cane Solution	Sulphuric Acid 5%	Tannic Acid 25%	Lactic Acid 5%	Hydrochloric Acid 5%
Z-Metal	0·016	0·00715	0·099	2·68	0·047	0·075	0·455
Grey Iron	—	0·1178	1·632	11·08	0·062	—	13·150
Malleable Iron	0·052	0·1680	1·628	27·57	0·087	1·190	11·181
Stainless Steel (12% Cr.)	0·001	0·0086	0·080	4·30	—	—	0·252

carbon particles function in much the same way as in graphitic steels, and Z-Metal, which in effect is a graphitic steel, has in many instances proved to be a superior beari g material because of this quality. The microstructure of the material which is in part responsible for many of its properties consists of hard particles of spheriodised cementite embedded in tough iron, giving a combination of high strength, wear resistance and satisfactory toughness.

Tensile strength and elongation at elevated temperatures and reduced

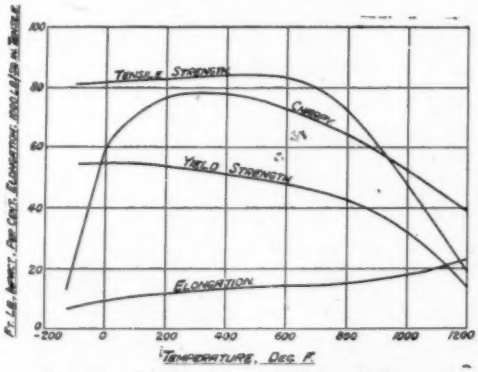

Fig. 1.—Physical properties of Z-metal at low and elevated temperatures.

temperatures, are also important properties and values for these properties and for impact strength are given in Fig. I. These values indicate that such properties are not substantially affected by a normal change in temperature from 0° to 700° F. (0° to 370° C.). The impact strength was determined on unnotched Charpy test bars. The fatigue or endurance limit is 14·5 tons per sq. in. (7 million reversals) and there is little difference between notched and unnotched test specimens. Compression tests conducted on a cylinder $\frac{15}{16}$ in. diameter by 3 in. long show a yield strength in compression of 23·6 tons per sq. in., and an ultimate compression strength of about 100 tons per sq. in. As regards corrosion the alloying element which makes the material corrosion resistant dissolves in the iron and has the property of forming a film which subsequently protects the metal from further corrosion. The relative corrosion rates of the alloy and of grey iron, malleable iron and stainless steel are given in Table I.

Z-Metal can be hot dip galvanised or otherwise surface treated, as by electroplating, without detriment to its properties. It can be flame or induction hardened, a hardness of Rockwell C 50 minimum, 500 Brinell being obtained to any reasonable depth when such hardening is applied. Fusion welding of the alloy is not recommended as a welded joint has practically no elongation. The maximum section thickness which may be cast in irons of this material is about $1\frac{1}{2}$ in., and the minimum as thin as $\frac{1}{8}$ in. The material also machines easily and finishes smooth and clean without chipping or tearing and takes a bright polish on grinding.

Applications for Z-Metal are in automobile crankshafts, camshafts and other parts; brake shoes and hands for railway work; union and coupling fittings and valve bodies; tools; and machine parts including gears, cranks, levers, nozzles, cams, connecting rods, etc.

Sea-Air Corrosion of Magnesium Alloys

By J. A. Peloubet

AT a testing station on the shore of the Atlantic Ocean in North Carolina, established by the Dow Chemical Co. in co-operation with the International Nickel Co., Inc., and the Carnegie-Illinois Steel Corp. a series of sea-air corrosion tests have been carried out on magnesium alloys. At this station test specimens of standard size, 3 in. × 6 in., 4 in. × 6 in., or multiples thereof, are held on test frames by means of electrical porcelain insulators in racks, set up 800 ft. from the mean tide line, with specimens inclined 30 deg. to the horizon. Data obtained are based upon tests of standard panels, riveted or welded panels and full size aircraft structures, exposed up to $2\frac{1}{2}$ years.

In Table I are given the weight loss, tensile loss and visual classification of the various magnesium alloys tested together with those of a few other metals listed for comparison. Values were obtained on individual test panels representing neither maximum nor minimum results. Sheet and

From *Metals and Alloys*, 1945, vol. 21, No. 5, pp. 1327–1333.

TABLE I.—COMPARISON OF VARIOUS METALS AND ALLOYS.

Alloy	Form	Years on Test	Corrosion Rate Mg/CM²/Day	Loss % Tensile Strength	Visual Classn-cations
Dowmetal M	Extrusion	2	0·007	Nil	3
„ J-1	„	2	0·003	4·0	1
„ O-1	„	2	0·002	3·3	1
„ Z-1	„	1	0·037	10·0	5
„ FS-1 h	Sheet	2	0·005	6·0	2
„ J-1 h	„	2	0·003	7·1	1
„ M	As Cast	2	0·009	Nil	4
„ H	„	2	0·007	1·4	2
„ H	H.T.	2	0·006	Nil	3
„ H	H.T.A.	2	0·005	0·5	2
„ H-1	As Cast	2	0·008	Nil	1
„ H-1	H.T.	2	0·008	Nil	2
„ H-1	H.T.A.	2	0·005	2·0	1
„ C	As Cast	2	0·006	Nil	2
„ C	H.T.	2	0·004	Nil	3
„ C	H.T.A.	2	0·004	Nil	2
„ C-1	As Cast	2	0·006	Nil	1
„ C-1	H.T.	2	0·003	Nil	2
„ C-1	H.T.A.	2	0·003	1·5	1
„ R	As Cast	2	0·005	Nil	2
„ R	H.T.	2	0·003	Nil	3
„ R	H.T.A.	2	0·003	Nil	2
„ R-1	As Cast	2	0·005	Nil	1
„ R-1	H.T.	1	0·003	0·5	1
„ R-1	H.T.A.	1	0·003	1·2	1
„ G-1	As Cast	2	0·006	Nil	1
„ G-1	H.T.	2	0·003	1·5	1
„ G-1	H.T.A.	2	0·002	1·0	1
„ R-1	Die Cast	2	0·002	Nil	1
38, Aluminium	Sheet	2	Nil	Nil	2
17 S.T. Aluminium	„	2	Nil	0·1	3
Clad 24 S.T. Aluminium	„	2	0·0003	0·2	1
Mild Steel	Plate	1	0·46	31·5	6
Galvanised Iron	Sheet	2	0·006	1·8	4

extrusion specimens were tested with ground surfaces while castings were machined. The specimens were not protected by chemical treatment or paint schedules. All wrought products except Dowmetal M were made up to contain only controlled amounts of impurities for the purpose of increasing corrosion resistance. Such alloys are given the designation 1, Iron and nickel in particular being kept below 0·005%. Cast Dowmetals H–1, C–1, R–1 and G–1 were experimental high purity cast alloys and Dowmetal C was a commercially cast alloy.

Based on a 2½ years exposure of unpainted panels, a dichromate treatment appears to protect Dowmetals FS–1 and J–1 somewhat better than a chrome-pickle treatment, while a galvanic-anodise treatment was visibly better than a chrome pickle on the M alloy. No failures were found on panels protected by aluminium varnish applied over a zinc chromate primer, but camouflage finishes chalked rapidly and had little or no protective value.

One and a half years' exposure of Dowmetal J–1 h (chrome-pickle) riveted with 56S, 2S and A 17 ST rivets, showed no galvanic-corrosion around the 56S rivets and definite attack with rings of corrosion product around the 2S and A 17 ST rivets. 56S rivets are therefore recommended for riveted Dowmetal structures. Corrosion products also formed in two or three months around A 17 ST rivets in contact with bare, chrome-pickled, or dichromate treated Dowmetal J–1 h. In eight months, failure was also noted around A 17 ST rivets contacting J–1 h alloy, dichromate treated plus two coats of zinc chromate primer plus two coats of aluminium pigmented varnish. Tests on assemblies of magnesium alloys and dissimilar metals showed no galvanic action in sea-water atmospheres, if protected by suitable junction sealers and paint schedules. Tests on bare metal assemblies indicated severe galvanic corrosion between magnesium alloys and the more noble metals such as copper and steel, while considerably less attack took place when magnesium alloy contacted aluminium alloys, galvanised iron or zinc. A series of bare Dowmetal M and J–1 panels were prepared in which various types of bolts were inserted into drilled holes and the assemblies exposed in duplicate for a period of six months. A comparison of the galvanic action caused by the various bolts is given in Table II, where the latter show the order of attack, *A* being the least.

TABLE II.—CONTACT CORROSION OF BOLTED PANELS.

Bold Material	Dowmetal	
	M	J 1
Steel	C	E
Cadmium Plated Steel	B	D
Zinc Plated Steel	B	C
Brass	B	E
Cadmium Plated Brass	B	E
Zinc Plated Brass	A	A
Cadmium Plated Steel + 3 S Washers	A	A
" " " + 17 ST "	A	A
" " " + 52 S "	A	A
Monel Metal "	C	E

It was found that arc-welded Dowmetal J–1 h sheet must be stress relief annealed to remove the locked-up residual welding stresses which promote stress corrosion cracking. Spot welds offered satisfactory corrosion resistance, if the welding electrodes were kept clean and deposition of copper on the sheet material avoided.

Extensive tests of the stress corrosion resistance of various magnesium alloys were carried out using both direct spring and eccentric loading of test bars. These tests showed that with unpainted alloys exposed to coastal atmospheres, Dowmetal FS–1 h was more resistant to stress corrosion cracking than J–1 h, and that stresses causing failure in either case were above usual design values.

A New Coating Thickness Gauge

By S. Lipson

LOCAL thickness measurement of coatings on steel by magnetic means is generally considered to be superior to other methods of coating-thickness measurement because of its rapidity and non-destructive nature. A number of instruments have been widely used for this purpose, but an alternative coating thickness measuring instrument (non-magnetic coatings on steel) has been developed at Frankford Arsenal. This new instrument requires a source of alternating current which is used to energise a solenoid containing a movable iron core. As this soft iron core is withdrawn from the field of the solenoid, the magnetic pull upon the core increases. If the solenoid is held in a vertical position over a coated steel article and lowered sufficiently to permit the lower end of the core to contact the surface, the distance through which it must be raised for the pull of the solenoid to overcome the attraction of the core for the ferromagnetic basis metal will vary inversely with the thickness of the coating.

The reproducibility of the instrument was determined by taking 100 readings at a single spot on the thickness standard (0·00053 in.). The results of this test show that the standard deviation for the scale readings was calculated to be 0·116. This, using the $\pm 3\,\sigma$ limit, is comparable to $\pm 4\%$ error for the thickness range.

From *A.S.T.M. Bull.*, 1945, No. 135, pp. 20–23.

Rhenium

IN 1869 Mendelejeff prophesied the existence of certain unknown elements and foretold their properties. In the seventh group of his famous table there were two vacant places under manganese, elements No. 43 and 75. In 1922 Ida and Walter Noddack of Berlin initiated a careful search, testing and analysing a host of widely scattered minerals, industrial products and by-products. After three years of intensive research they discovered element No. 75 in a sample of Norwegian gadolinite, an yttrium earth silicate.

Contrary to expectations, very little Re was found in manganese ores. But the Noddacks discovered appreciable quantities of Re in the Mansfield electrolytic copper slimes. These slimes contained relatively large quantities of molybdenum, now a recognised common associate of copper. Today the chief source of Re is the molybdenite ores. The MoS_2 deposit at Middle Inlet, north Wisconsin, contains about 50 parts of Re per million parts of ore. Before the outbreak of World War II the Vereinigten Chemischen Fabriken were yearly producing 120 kg. $KReO_4$.

In one of the processes for the recovery of Re from molybdenite ore this is roasted at 600° C. About 90% of the Re is volatilised as Re_2O_7. The flue dust is dissolved in water and reprecipitated as $KReO_4$ by the addition of KCl. The oxide and $KReO_4$ are readily reduced with hydrogen, the final heat being about 1,000° C.

The specific gravity of Re is 21·4 as against 19·6 for tungsten. The atomic weight is 186·3 (W = 183·92). Its crystals are hexagonal. The melting point is 3,167° C. (W = 3,387° C.). It is ductile cold. It is highly resistant to HCl and HF but is slowly attacked by a moist atmosphere. The chlorides $ReCl_6$, $ReCl_7$ and $ReCl_8$ have been isolated. It does not react with nitrogen at 1,000° C. It forms alloys with W, Ni, Co, Ta, Cb, Pt, Os, and Au.

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